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CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
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TECHNICAL SUPPORT DOCUMENT FOR
STAFF PROPOSAL REGARDING REDUCTION OF GREENHOUSE GAS EMISSIONS FROM MOTOR VEHICLES

HFC-134A AS AN AUTOMOTIVE REFRIGERANT -- BACKGROUND, EMISSIONS, AND EFFECTS OF POTENTIAL CONTROLS

July 21, 2004

APPENDIX C.3

HFC-134a as an Automotive Refrigerant --
Background, Emissions, and Effects of Potential Controls

Contents

SECTION A

Previous Work by Others

<u>Schwarz & Harnisch, 2003</u>

This study was performed by Oko-Recherche and Ecofys for DG Environment of the European Commission (EC).

The amounts of HFC-134a in 276 vehicles in Portugal, Germany, and Sweden were compared to their design capacities. The air conditioning (AC) systems of all the vehicles were in their original conditions (undamaged and never serviced). The vehicle ages ranged from 1 to 6 years in age (1996 to 2001 MYs).

The loss of charge averaged over vehicles and ages was 52 grams per year, which equaled 6.9% of the design capacity per year. The result was substantially greater among vehicles that were one year old (10% per year) than among vehicles of any other age (5% to 7% per year over 2 to 6 years). The loss rates differed somewhat by country, but the differences were not completely explainable by climate. (The loss rate was highest in Portugal, but the rate in Sweden exceeded that in Germany.) Significant differences were seen among vehicle brands.

This work appears to be carefully done. However, the applicability to California is questionable because there were very few American- or Japanese-made vehicles in the test sample.

<u>Schwarz, 2001</u>

This study was conducted by Oko-Recherche for the German Federal Environment Office.

Historical data on 841 vehicles serviced at 19 German auto dealerships were analyzed to estimate HFC-134a leak rates. The amounts of HFC-134a in the systems were compared to the design capacities.

The vehicles ranged in age from new to seven years old. For vehicles whose HFC-134a charges were at least 60% of their design capacities, the preceding leakage was assumed to have been slow and steady (“normal” leakage). In an analysis that involved assumptions that ARB staff finds questionable, the author derived an average (over vehicles and ages) “normal” leak rate of 6.3% of the design charge per year .

We do not regard this result as applicable to the general vehicle population in Germany (let alone in the US) because the test vehicles were not a random sample of all the vehicles (either on the road or among the dealerships’ customers) whose charges are at least 60% of capacity. Most of the vehicles were at the auto dealerships for inspection or repair of their AC systems. Thus, their leak rates were probably biased high relative to all “normal” leakage.

For vehicles with complete losses of charge, the leakage was assumed to have occurred suddenly (“irregular” leakage, from failures and accidents). The author assumed that (1) all such vehicles are identified during the mechanical inspections conducted by a dealership, and (2) the population of vehicles receiving such inspections is a random sample from the on-road population. The author adjusted the observed tallies of inspections according to statistics on the relative frequencies among vehicle ages for the owners’ use of dealerships for auto maintenance. The observed number of vehicles with complete loss divided by the adjusted tally of inspections yielded an estimate that 1.9% of design capacity is lost per year from “irregular” leak events.

Surveys in 1997 and 2000 by Mobile Air Conditioning Society

Periodically, the Mobile Air Conditioning Society invites its member shops to report data related to the repairs performed on their customers’ AC systems. The list of responding shops differs from year to year. Respondents report data from vehicles of their choice on a form supplied by the Society.

The ARB staff obtained and analyzed the data obtained by the Society in 1997 and 2000. *In both years, about 88% of the reported vehicles were Amercian-made.* Data and results pertinent to this report are shown in the following tables.

Participating Shops

Shop	Locale	HFC-134a Vehicles*	Period**
		1997 survey	
1	Wisconsin	66	18 Jun - 7 Aug
2	Louisiana	50	10 Jul - 06 Oct
3	So. Calif.	46	unknown
4	Florida	29	9 Jul - 6 Sep
5	Florida	22	unknown
6-17	various	103	18 Jun - 01 Oct
		2000 survey	
1	So. Calif.	40	unknown
2	Virginia	38	“
3	Pennsylv.	44	“
4	Arizona	54	“
5	Arizona	43	“
6-10	various	86	“

* HFC-134a as original equipment, 1993 and later MYs

** Data not taken continuously over the period.

As-Received Vehicle Characteristics

Age yrs *	No. of Vehicles 1997	No. of Vehicles 2000	Avg. Miles/Yr ** 1997	Avg. Miles/Yr ** 2000	% with No Pressure 1997	% with No Pressure 2000	Avg. Missing Charge^ (no. of vehicles)	Avg. Missing Charge^ as % of capacity
7	0	23	--	14,700	--	48	4	76
6	0	72	--	14,700	--	28	16	26
5	0	92	--	16,700	--	29	29	27
4	72	61	18,100	21,300	14	43	14	45
3	142	33	21,100	19,800	20	21	4	23
2	75	17	28,300	29,200	21	24	2	33
1	21	7	30,900	32,800	29	57	1	13
0	6	0	16,100	--	17	--	0	--
Ages 1-4, combined	310	118	23,100	22,400	19	46	Mean:	32

* calendar year - model year ** odometer/age ^ data in 2000, only

The samples were consistent between the two years when considered for the ages of vehicle that are in common (1 to 4 years). However, there are notable inconsistencies between years in the fractions that were received with no refrigerant pressure. Data for the California shop (not shown) were consistent with the overall data.

The mean loss of charge calculated by staff among 70 vehicles with appropriate data (measurements of both amount evacuated and amount recharged) was 32 percent of the system capacity. However, the Society analyzed the same dataset and reported an average loss of 57% from 65 vehicles. Since the Society's analysis is no longer extant, the discrepancy cannot be examined.

The mean capacity, as determined by the amount of HFC-134a recharged after service to about 200 vehicles in each year, was one kilogram.

System Capacity

MY	No. of Vehicles 1997	No. of Vehicles 2000	Mean Cap., kg. 1997	Mean Cap., kg. 2000
93	49	11	.96	1.16
94	96	42	1.01	.91
95	49	68	1.05	1.03
96	16	46	.91	1.04
97	4	17	.86	1.00
98	0	10	--	1.14
99	0	4	--	.76
All data	214	198	1.00	1.01

Siegl et al., 2002

Ford Motor Co. measured HFC-134a emissions from 28 light-duty vehicles of model years 1997 to 2000. The mean engine displacement was 4.13 liters.

Measurements were taken per the federal extended (2-day) diurnal test procedure. All the data were taken with the engine off, following the urban dynamometer driving cycle and a 6-hour soak (vehicle cold at the initiation of the test).

The mean leak rate was 0.07 grams/day (std.dev. = 0.07). The authors associated the data with odometer readings but not with model year. The vehicles are clustered in odometer ranges 0 to 50,000 miles (22 vehicles) and 115,000 to 141,000 miles (6 vehicles). The mean leak rates for the two groups are 0.05 and 0.16 g/day. The difference is significant at the 0.002 level.

The authors argue that if (1) vehicular HFC-134a leakage dominates leakage from all refrigeration worldwide and (2) the measurements in the Ford work apply worldwide, the 0.07 g/day value is roughly consistent with estimates of the rate of increase of the global mean concentration of HFC-134a in the troposphere.

Stemmler, 2003

The Swiss Federal Laboratories for Materials Testing and Research estimated the average emission rate among vehicles travelling in the Gubrist Tunnel in Switzerland in the fall of 2002 by measuring the mass rate of outflow of HFC-134a from the tunnel. The authors assumed that 45 percent of the vehicles in the tunnel were equipped with HFC-134a systems. Their result was 14 mg/hr/HFC-134a vehicle. There is no information on how many of the AC systems were in operation in the tunnel.

Barrault et al., 2003

A 2003 report for the European Commission summarizes additional studies done in Europe. The sources discussed in the report employed a variety of methods to obtain and analyze data. Some sources did “bottom-up” analyses based on measured leak rates from AC components. The analyses appear to have used scant data and significant assumptions. The EC report does not cite the conditions and methods for measuring leakage.

The results reflected in the EC report are:

- Emissions from fittings and crimps and through hose materials are proportional to pressure ^{X} where $1 < X \leq 2$.
- Emissions from those sources average 18 grams/year (bottom-up).
- Emissions from compressor seals are higher when the compressor is running than when it is idle; the emissions depend on the running speed.

- Emissions from compressor seals are from 3 to 20 grams/year (bottom-up).
- A Dutch study estimated average annual leakage rate of 9% of capacity per year for private cars (method of estimation unstated).
- A study in Sweden indicated annual use at 3 to 11% of system capacity. (Apparently) results of a survey of consumption by repair shops were extrapolated to the entire country and divided by the estimated Swedish population of HFC-134a vehicles. (The mean mass rate as inferred by Barrault was 57 grams/year.)

SECTION B

Quantification of Vehicular HFC Emissions

Introduction

Given enough time and resources and a consensus on technical procedures, one would want to model annual and lifetime emissions on the basis of direct emission test data. A few such data exist. However, as explained in Section A below, the phenomenon of refrigerant leakage appears to be too complex to enable estimating annual or lifetime emissions from the test data on hand. Instead, the staff has relied on alternative types of data and analyses to quantify the two emission measures indirectly.

Section A discusses refrigerant emissions and possible approaches to estimating them. Sections B and C provide the details and results of the analyses that the staff has performed.

A. Overview of Refrigerant Leakage and Means to Estimate It

Complexity of Leakage

Many AC components can leak. According to data provided to staff by the Mobile Air Conditioning Society, taken during their 1997 and 2000 surveys of commercial AC repair shops, 40 to 50 percent of identified leaks (but not necessarily the mass of leakage) occur in the compressor, the hoses, or the hose couplings. Other leak points are the expansion valve (or orifice tube), receiver-drier (or accumulator), control switch, service port, and o-ring.

At least some vehicles begin to lose their refrigerant early in their service lives. [1] Presumably, such leakage is slow and steady, via mechanisms such as permeation through elastomeric hoses and seals. Such a leak rate may increase gradually through age-related deterioration. However, it is likely that in some vehicles, additional leakage is rapid, with a sudden onset that occurs some time after the vehicle has been produced. For example, there can be a mechanical failure, such as failure of a seal or puncture of the condenser, that releases refrigerant over just a few hours or days. Thus, the rate of leakage can vary substantially and rather suddenly during any vehicle's lifetime.

At any calendar age, vehicles have widely different accumulations of hours of AC operation, depending on the climate and the drivers' habits. This variable may affect the time of the onset of leakage that is due to deterioration. That onset may also be affected by varying quality of materials across vehicle makes and models. Therefore, not only can leakage be variable through a vehicle's life, the timing of emission episodes may vary substantially among vehicles. Very little information about these factors is available.

In addition, leakage varies with operating temperature [9] the ambient temperature [10, 11] and between the AC (compressor) on and the AC off [11]. These variables affect the pressure of the refrigerant and, thus, affect the leak rate. Again, there is insufficient information on these factors. (How AC on/off should be controlled in testing to represent typical real-world operation has not been addressed adequately.)

In consideration of the above, we conclude:

- Instantaneous measurements of leakage from individual vehicles (e.g., diurnal SHED testing) are not now a practical means for characterizing on-road emissions across the fleet, through the year, and through vehicular lives.

  -- We do not know what vehicles and test conditions should be used to represent the real-world factors that influence the leak rate. Therefore, an impractical number of vehicles x model year x operating condition x ambient temperature x age would have to be tested to ensure that all important effects were captured in an average of test results.

  -- A laboratory test of a few hours duration would be unlikely to capture episodic emissions (due to ruptures, accidents, etc.)

- Therefore, emission estimates should be based on data that reflect refrigerant losses accumulated over substantial in-use periods (years) for large aggregations of vehicles.
- The periods of loss measurement should, in aggregate, cover the entire range of useful lives of vehicles.

<u>Estimating Accumulated Loss of Refrigerant</u>

Four types of analysis can be used to estimate accumulated loss. The first type directly measures loss over time from specific vehicles. The other three infer loss from various statistics about service events among large populations of vehicles. The staff has used information from all of them to varying degrees, either to make emission estimates or to provide corroboration of factors in the estimates. The types of analysis are summarized generically as follows.

1. *Measuring loss of charge over time from each vehicle in a sample*. If one knows the time when a vehicle's AC system was last filled to its design capacity, the difference between that capacity and the current charge, divided by the elapsed time, is the average emission rate over the period. If one had data of this sort from a large sample of vehicles that represents the composition of the on-road fleet, and if the age intervals between service events covered all the ages of vehicles on the road (practically, 0 to 16 years), one could use the data to estimate annual emissions (other than losses when vehicles are dismantled).

   One difficulty here is finding vehicles that meet the criteria of a known last date of filling the system. This has been practical only for late-model vehicles that have never been serviced since their manufacture. A study in Europe [1] found an average refrigerant loss rate of 7% of charge per year among 276 never-serviced vehicles of ages up to six years. (See Section A, Previous Work by Others.) The study was carefully done, and the results appear to be valid for their range of applicability. However, the vehicles were almost all of European manufacture; and neither the span of model years (six) nor the portions of vehicle lifetimes examined (all started at age 0) is sufficient to characterize the on-road fleet in California or the lifetime of a vehicle. Therefore, the staff thinks that the result of 7 percent loss per year should not be assumed, a priori, to apply to vehicles other than new European vehicles.

No work like this in the U.S. is known to the staff.

2. *Analyzing refrigerant consumption by fleets*. If a fleet of vehicles is serviced in-house, the amount of HFC-134a used in AC servicing over an extended period, divided by the fleet population, equals the average loss per vehicle over the period (plus any fugitive losses incidental to servicing).

   There is not a one-to-one relationship between replacement and leakage during a period. The leakage that was replaced by a re-charge occurred over a unknown span of time *before* that event, anywhere from one day up to the entire life-to-date of the vehicle. However, since AC repair activity for a large fixed vehicle population presumably is similar year-to-year, the annual refrigerant use rate by a fleet of a fixed composition can be used to estimate the average annual leakage rate. (See Section B-1 for more explanation.)

3. *Integrating age-specific AC recharging incidence.* As described in detail in the next section, data from fixed fleets can yield estimates of the fraction of vehicles that receive recharges to their AC systems during a year, as a function of age. The sum of these annual fractions out to some age is an estimate of the total recharges of an "average" vehicle in that fleet out to that age. Other data, from commercial repair shops and fleets, allow calculation of the average amount of refrigerant used per recharge. The product of the two average statistics (recharge count and amount per recharge) is the estimated loss of charge out to the oldest analyzed age.

4. *Surveying vehicle owners on repair incidence in vehicle lifetimes to date.* Original owners of vehicles can be asked how many times their vehicles have ever needed recharges. If the average response is well-behaved as a function of vehicle age, the average for the oldest model in the survey can be accepted as an alternative count of recharges out to that age.

<u>Universal Limitations</u>

Regardless of the source or type of data, *there are no data for vehicles older than about nine years (1994 MY [1]) that were sold with HFC-134a systems.* Therefore, to estimate annual emissions as if all vehicles were OEM HFC-134a vehicles (as will

[1] All vehicles of model year 1995 or later have been sold with HFC-134a systems. Some 1993 vehicles and most 1994 vehicles also were sold with HFC-134a, but the exact numbers are unknown.

virtually be the case in 2009) or to create a lifetime emission model, one must either (1) extrapolate estimates based on data for pre-1994 vehicles to vehicles older than 1994 or (2) rely on data taken for older vehicles that have been converted to HFC-134a. We have done the latter.

Another limitation occurs when, as in our analysis, all the data for the analysis are taken in one calendar year. In that case, all the statistics derived for distinct ages of vehicle could also be labeled as statistics for distinct model years (e.g., 1 year old = 2002 MY, 2 years old = 2001 MY, etc.). That is, when data are all taken at essentially the same time, *the effects of vehicle age are totally confounded in the data with any effects of model year* (e.g., changes in the design, quality of materials, or quality of assembly). Therefore, the results of the analyses shown below are "snapshots" of emissions from the fleet as it was composed in 2003 and of the emissions during a "lifetime" that is composed of one year from the 2003 MY, one year from the 2002 MY, etc. There is no way to isolate any model-year trends that may be imbedded in the data; so there is no basis in the data to adjust the results to apply specifically to some future year such as 2009.

Analyses Presented Here

The staff has used analysis types 2, 3, and 4 (above) to make a model for the lifetime emissions for a "typical" vehicle and two independent estimates of the current annual emissions. Section B of this chapter describes the model and the derivation of its parametric values. Section C describes the surveys of vehicle owners that are one source of model-building data. Section D describes the estimation of annual emissions. It compares the estimates to empirical work.

B. Lifetime Leakage Model

The ARB staff has characterized HFC-134a emissions from vehicular air conditioners with a simple mass balance on a vehicle during its life. The emissions consist of (1) the leakage from the AC system during the life of the vehicle, (2) any fugitive loss from the system that is incidental to repair work in which the system is opened to repair a source of leakage[2], and (3) any residual charge that escapes as the system is disassembled when the vehicle is scrapped. By mass balance, these emissions are equal to the initial HFC-134a charge to the AC system, less the amount recovered by the auto dismantler, plus the amount of fresh HFC-134a re-charged to the system during the life of the vehicle. That is: any leakage over the life of the vehicle must come from either the initial charge or its replenishments, and all HFC-134a is either leaked, recovered at scrapping, or emitted at scrapping (or in an accident).

In symbols:

$$LVE = C * (1 - g + N * f)$$

[2] Such fugitive losses cannot be distinguished from vehicular leakage in the data we have used. The staff's observation of professional AC servicing indicates that fugitive losses are minor at fleet garages

where: LVE is lifetime emissions (mass) from the vehicle

C is the system capacity (mass) for HFC-134a

"1" represents the initial charge

g is the fraction (of a full charge) recovered at the time of scrapping

N is the number of times a vehicle is recharged during its life

f is the fraction of charge missing (leaked) before the recharge

Regarding the proportionality of LVE to system capacity: There is limited evidence that emission *rates* depend in part on the system capacity.[3] That is reasonable since systems with greater capacities presumably have larger surface areas of components that are susceptible to developing leaks, such as condensers, evaporators, hoses, and seals. However, the equation above is *not* a mechanistic or statistical model for leakage; the right-hand side LVE is the net amount of HFC-134a *introduced to* the system during its lifetime. That amount is intrinsically related to the capacity, with the initial fill identically equal to the capacity.

The parameters for the model as it is applied to the "average" vehicle have been estimated separately by averaging data from different sources for each parameter.[4] The average values that we have derived by this means are:

C = 951 grams

g = 0.085 fraction recovered at scrapping

f = 0.52 fraction empty before recharging

N = 1.0 recharges per vehicle life of 16 years

resulting in:

LVE = 1.36 kg per 16-year lifetime

The rest of this Section B details the derivations of these numbers.

It is important to note that these values have been derived mostly from fleet vehicles, whose nature, use, and maintenance may be atypical of most on-road vehicles. The importance of this caveat is probably greatest for N. N may reflect the kind of use of the vehicles and the maintenance practices of the owners. Certainly, the use of vehicles in government or industrial fleets is not typical of private vehicle use. Also, N may be a

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and commercial AC shops, which recover and re-use the refrigerant from incoming vehicles. However, the losses during a "do-it-yourself" repair could be great. We have not attempted to estimate such loss.

[3] A study in Europe [1], using 276 new vehicles, measured a mean annual loss of charge somewhat more than proportional to capacity.

[4] In the mathematical ideal, one would measure C, g, f, and N (lifetime) for many vehicles, compute LVE for each vehicle, and average the LVE's over the vehicles. However, that would be impractical.

function of the origin of vehicles (e.g., U.S. vs. Asia vs. Europe). The fleets that provided data for the analysis are almost entirely composed of US-made vehicles, whereas the on-road fleet in California is about half US-made. The value obtained for C exceeds the mean capacity of recent Japanese vehicles [12].

Overview [5] of Our Methods and Data for Estimating N

The staff has used two independent approaches to estimating N:

- Estimating the average *annual* frequency of recharging (N', fraction of vehicles that receive recharges during a year) as a function of age, out to 16 years. (According to the "survival rates" in EMFAC, the average vehicular lifetime in California is 16 years. See "Derivation of 16-years as Average Vehicle Life".) Summation of these annual estimates yields the estimate of N. That is, $\sum_{1}^{16} N' = N$
- Surveying original owners of vehicles on the number of recharges their vehicles have received since the vehicles were new. (Section C describes the surveys.)

The relationship of the average frequency of recharges to average leakage is discussed in Section B-1.

Our three sources of data for estimating N (or N') are described as follows.

1. Fleet Data Repair Data. ARB received collected data from 10 commercial or government fleets on:

- recharges of AC systems over 12-month periods by the fleet maintenance shops
- the compositions of the fleets containing the recharged vehicles

Table 1 describes the fleets that reported the 12-month data and compares them to the on-road fleet. The vehicles were light- or medium-duty vehicles. Data from the City of Stockton fleet were not included in the analysis because the counts of recharges, as fractions of vehicles in each age category, were much greater than those of any other fleet.[6] We suspect that the Stockton data confound recharges with AC service events that did not involve recharges, despite our attempt to identify and remove such events. (Data from the other fleets were more amenable to culling inappropriate events.)

The fleets are more weighted toward pickup trucks (especially the heavier pickups), SUVs, and vans than is the on-road fleet, and they consist almost entirely of U.S. makes. As vehicles in industrial and government use, their patterns of use differ from those of personal vehicles. Many of the sedans are police cars (Ford Crown Victorias). These inconsistencies with the on-road fleet might introduce biases.

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[5] Greater detail of the analyses is in the succeeding sections.

[6] Variability in N' among fleets is discussed in the next section.

Table 1. Statistics on Fleets that Provided AC Recharging Data

Fleet	Location	No. Vehicles*	Model Years range	Model Years mean	Fractions of Fleet PC	Fractions of Fleet Trucks^	Fractions of Fleet US-made
Verizon	various in Calif.	2,196	1989-2002	1997.7	30%	70%	100%
City of L.A.	Los Angeles	3,485	1985-2003	1998.4	45%	55%	90%
Kern Co.	~ Bakersfield	720	1985-2002	1998.4	67%	33%	>95%
CSAA	3 in Calif.	729	1988-2002	1999.0	84%	16%	100%
Riverside Co.	~ Riverside	2,842	1985-2002	1998.6	65%	35%	>95%
San Joaquin Co.	~ Stockton	990	1985-2002	1998.0	51%	49%	~95%
City of Modesto	Modesto	443	1994-2003	1999.1	43%	57%	~99%
Stanislaus Co.		582	1994-2003	1999.4	63%	47%	98%
City of Bakersfield	Bakersfield	595	1994-2003	1991.1	42%	58%	~99%
	Aggregated fleets:	**12,582**	**1985-2003**	**1998.3**	**52%**	**48%**	**>95%**
Calif. on-road (per EMFAC)			*1985-2003*	*1995.5*	*60%*	*40%*	*49%***
City of Stock-ton (not used)	Stockton	525	1985-2003	1996.9			

* numbers of vehicles used in this analysis. All vehicles of MY < 93 and unknown numbers of MY 1993 & 1994 were sold with Freon as the refrigerant. Only those retrofit to use HFC-134a are included here.

** from staff's analysis of 250,000 1993-2003 vehicles randomly sampled from DMV files. (See "Analysis of 500,000-Vehicle Random Sample for DMV Records".)

^ pickups, SUVs, and vans

The fact that the aggregate sample is younger than the on-road fleet is not a concern because the analysis was conducted by model year.

The data from the fleets are associated with fixed and known populations of vehicles, (the majority of which did not require service during the year). Thus, the counts of recharges at fleets can be divided by the population numbers to yield estimates of absolute annual recharge frequencies (recharges/vehicle/year).

The fleet data contain no information about vehicles in the general population that leak substantially but do not receive professional service. These include vehicles whose owners do not bother to repair their AC systems (for which N = 0) and vehicles that receive do-it-yourself recharges.[7] Since HFC-134a is legal and inexpensive as an after-market product, some people may merely refill leaking HFC-134a systems as often as necessary rather than pay to have leaks found and the leaking parts replaced. Thus, for some vehicles not seen in our data, the actual "N" may be larger than what is deduced from the data. On the other hand, our analysis may over-estimate N' for old vehicles because private owners may not repair them as often as fleet owners do.

2. Survey of Cal/EPA Employees. All California Environmental Protection Agency (Cal/EPA) agency staff who are original owners of HFC-134a vehicles were invited to complete an online survey. The main goal of the survey was to acquire data on the cumulative number of AC services versus model year (age). The survey form is shown in [Doc D]. 678 valid responses were recorded electronically. They provide an alternate means of estimating N, shown in Section C.

3. Survey of U.S. EPA Employees. A similar survey was conducted among employees of some offices of the United States Environmental Protection Agency (U.S. EPA). Responses were invited from all original owners of vehicles, regardless of the model year or refrigerant. 288 responses were recorded.

Details of Estimating N from Fleet Data

Tables 2.a to 2.j show the model-year breakdowns of the HFC-134a recharges and the fleet populations for the fleets that provided data for 12-month periods. The quotients (recharge/vehicles) are N', the annual recharge "frequencies" (fractions) by model year. "Age" refers to the assumed mean age of the vehicles of a model year, relative to the mid-point of the 12-month data period reported by the fleet. We assume that the mean date of manufacture of a model year was April of the corresponding calendar year.

[7] When a vehicle is serviced non-professionally (without recovery of the system's content), the fugitive emissions during the service may rival or even exceed the leakage preceding the service. Such emissions are not reflected in our analyses.

Table 2. Data and N' Values by Fleet

a. Verizon

Period: Jan 02 - Dec 02

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1989	13.2	2	3	0.667
1990	12.2	0	2	0.000
1991	11.2	1	11	0.091
1992	10.2	4	19	0.211
1993	9.2	2	27	0.074
1994	8.2	3	30	0.100
1995	7.2	40	367	0.109
1996	6.2	6	102	0.059
1997	5.2	25	498	0.050
1998	4.2	11	536	0.021
1999	3.2	3	170	0.018
2000	2.2	0	91	0.000
2001	1.2	0	175	0.000
2002	0.2	0	165	0.000
	All veh:	97	2196	0.044

b. City of Los Angeles

Period: Jul 02 - Jun 03 '03

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1985	17.7	0	9	0.000
1986	16.7	0	7	0.000
1987	15.7	0	7	0.000
1988	14.7	0	17	0.000
1989	13.7	5	84	0.060
1990	12.7	0	14	0.000
1991	11.7	1	35	0.029
1992	10.7	4	59	0.068
1993	9.7	2	55	0.036
1994	8.7	2	68	0.029
1995	7.7	16	277	0.058
1996	6.7	30	241	0.124
1997	5.7	8	342	0.023
1998	4.7	15	470	0.032
1999	3.7	3	243	0.012
2000	2.7	4	505	0.008
2001	1.7	1	429	0.002
2002	0.7	0	220	0.000
2003	0	0	403	0.000
	All veh:	91	3485	0.026

c. Kern County

Period: 4/22/02 - 4/21/03

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1985	17.5	0	3	0.000
1986	16.5	0	2	0.000
1987	15.5	0	2	0.000
1988	14.5	0	2	0.000
1989	13.5	0	4	0.000
1990	12.5	1	3	0.333
1991	11.5	1	22	0.045
1992	10.5	1	14	0.071
1993	9.5	1	11	0.000
1994	8.5	1	10	0.100
1995	7.5	3	45	0.067
1996	6.5	3	48	0.063
1997	5.5	4	116	0.034
1998	4.5	1	31	0.032
1999	3.5	1	57	0.018
2000	2.5	0	84	0.000
2001	1.5	4	152	0.026
2002	0.5	0	114	0.000
	All veh:	21	720	0.029

d. CSAA

Period: Jun 02 - May 03

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1988	14.7	0	2	0.000
1989	13.7	0	0	0.000
1990	12.7	0	1	0.000
1991	11.7	0	4	0.000
1992	10.7	0	2	0.000
1993	9.7	0	5	0.000
1994	8.7	0	4	0.000
1995	7.7	3	8	0.375
1996	6.7	0	12	0.000
1997	5.7	1	61	0.016
1998	4.7	5	208	0.024
1999	3.7	0	1	0.000
2000	2.7	3	209	0.014
2001	1.7	4	210	0.019
2002	0.7	0	2	0.000
	All veh:	16	729	0.022

e. Riverside County

Period: Jul 02 - Jun 03

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1985	17.7	1	11	0.091
1986	16.7	0	8	0.000
1987	15.7	0	3	0.000
1988	14.7	0	11	0.000
1989	13.7	1	18	0.056
1990	12.7	3	37	0.081
1991	11.7	10	49	0.204
1992	10.7	1	23	0.043
1993	9.7	2	55	0.036
1994	8.7	16	100	0.160
1995	7.7	27	193	0.140
1996	6.7	11	71	0.155
1997	5.7	5	79	0.063
1998	4.7	13	218	0.060
1999	3.7	37	615	0.060
2000	2.7	16	500	0.032
2001	1.7	13	399	0.033
2002	0.7	6	452	0.013
	All veh:	162	2842	0.057

f. San Joaquin County

Period: Jul 20, 02 - Jul 19, 03

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1985	17.8	0	7	0.000
1986	16.8	0	14	0.000
1987	15.8	0	10	0.000
1988	14.8	0	13	0.000
1989	13.8	2	13	0.154
1990	12.8	2	17	0.118
1991	11.8	5	25	0.200
1992	10.8	5	20	0.250
1993	9.8	5	23	0.217
1994	8.8	1	30	0.033
1995	7.8	5	21	0.238
1996	6.8	1	42	0.024
1997	5.8	3	59	0.051
1998	4.8	6	67	0.090
1999	3.8	6	192	0.031
2000	2.8	5	149	0.034
2001	1.8	3	136	0.022
2002	0.8	0	152	0.000
	All veh:	49	990	0.049

g. City of Stockton

Period: 7/1/2002 to 6/30/03

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1985	17.7	1	3	0.333
1986	16.7	0	5	0.000
1987	15.7	0	9	0.000
1988	14.7	0	7	0.000
1989	13.7	3	8	0.375
1990	12.7	0	7	0.000
1991	11.7	7	27	0.259
1992	10.7	3	24	0.125
1993	9.7	11	31	0.355
1994	8.7	7	33	0.212
1995	7.7	13	38	0.342
1996	6.7	6	29	0.207
1997	5.7	10	55	0.182
1998	4.7	1	28	0.036
1999	3.7	11	60	0.183
2000	2.7	0	26	0.000
2001	1.7	5	56	0.089
2002	0.7	1	24	0.042
2003	0	1	55	0.018
All veh		80	525	0.152

h. City of Modesto

Period: 7/1/2002 to 6/30/03

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1994	8.7	3	12	0.250
1995	7.7	2	34	0.059
1996	6.7	1	19	0.053
1997	5.7	1	34	0.029
1998	4.7	3	43	0.070
1999	3.7	2	49	0.041
2000	2.7	4	53	0.075
2001	1.7	2	84	0.024
2002	0.7	0	91	0.000
2003	0	0	24	0.000
	All veh:	18	443	0.041

i. Stanislaus County

Period: 7/1/2002 to 6/30/03

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1994	8.7	0	12	0.000
1995	7.7	0	31	0.000
1996	6.7	1	53	0.019
1997	5.7	1	43	0.023
1998	4.7	0	32	0.000
1999	3.7	4	69	0.058
2000	2.7	2	111	0.018
2001	1.7	3	133	0.023
2002	0.7	0	61	0.000
2003	0	0	37	0.000
	All veh:	11	582	0.019

j. City of Bakersfield

Period: 7/1/2002 to 6/30/03

MY	Age	Recharges in 12 mo.	Vehicles in Fleet	N'
1994	8.7	2	8	0.250
1995	7.7	5	15	0.333
1996	6.7	23	110	0.209
1997	5.7	11	76	0.145
1998	4.7	5	57	0.088
1999	3.7	2	57	0.035
2000	2.7	8	40	0.200
2001	1.7	1	89	0.011
2002	0.7	0	86	0.000
2003	0	0	57	0.000
	All veh:	57	595	0.096

In general, the events that were reported by the fleets are just those in which HFC-134a was added to vehicles. However, for the fleets from City of Stockton and San Joaquin County, all AC-related service events for HFC-134a vehicles were reported. The staff has culled from those reports (and the tables) the events that clearly involved only repairs of AC components that cannot leak refrigerant (e.g., fan motors and control functions). However, the events tallied in the tables (especially for Stockton) may still include some inappropriate events.

Some vehicles in the 1993 and 1994 MYs do not have HFC-134a systems as original equipment. For 1992 and older MYs, none of the vehicles have original HCF-134a systems. For several of the fleets, we understand that most, if not all, of the tabulated vehicles have been converted to HFC-134a, and we have kept those vehicles in the analysis. In the cases where no vehicles older than 1994 are shown in the tables, we understand that many of the older vehicles have *not* been converted, so we have deleted all of them from the analysis. Overall, we think that there are few R12 vehicles in the tabulated fleet populations.

Figure 1 shows all the values of N' from the individual fleets.

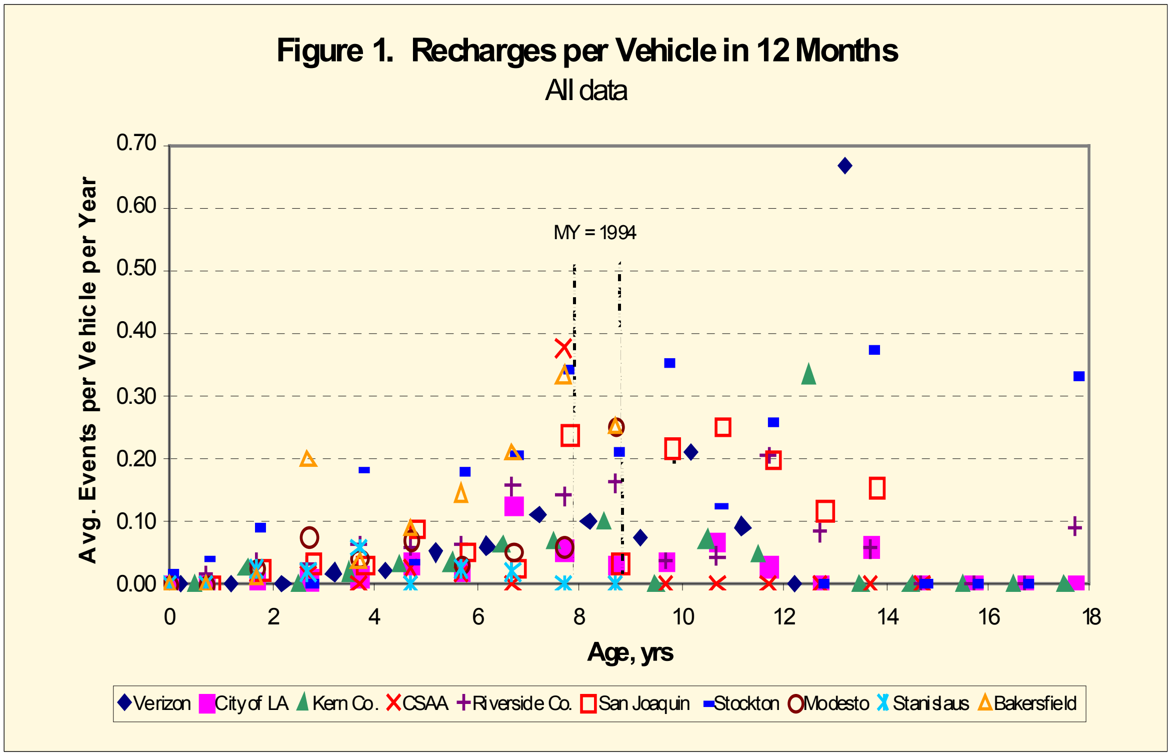


Figure 2 is the same plot less all values derived from fewer than 30 vehicles for a model year. Its purpose is to reduce the scatter enough to show that the values for the City of Stockton are high outliers. All Stockton data have been excluded from the analysis.

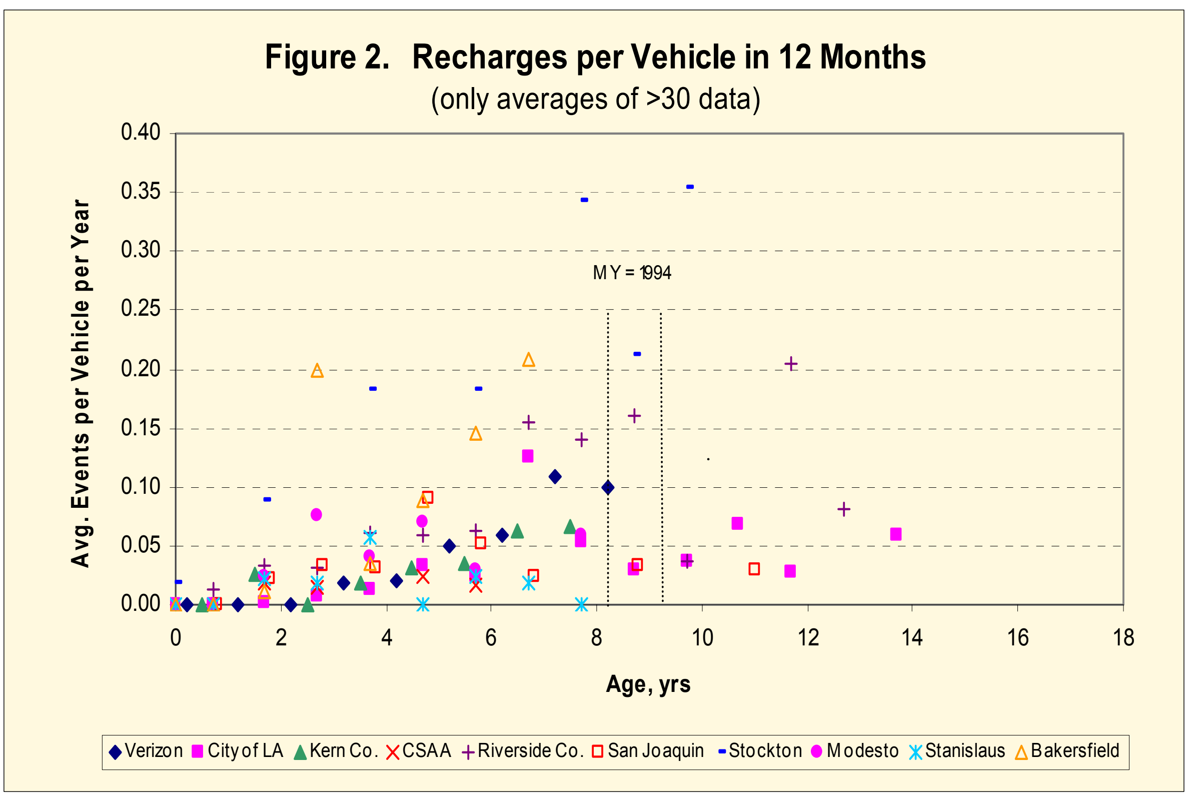


Table 2.k shows the results for the combined data, excluding the data from Stockton.

Table 2 k. N' from Combined Fleet Data (excluding Stockton)

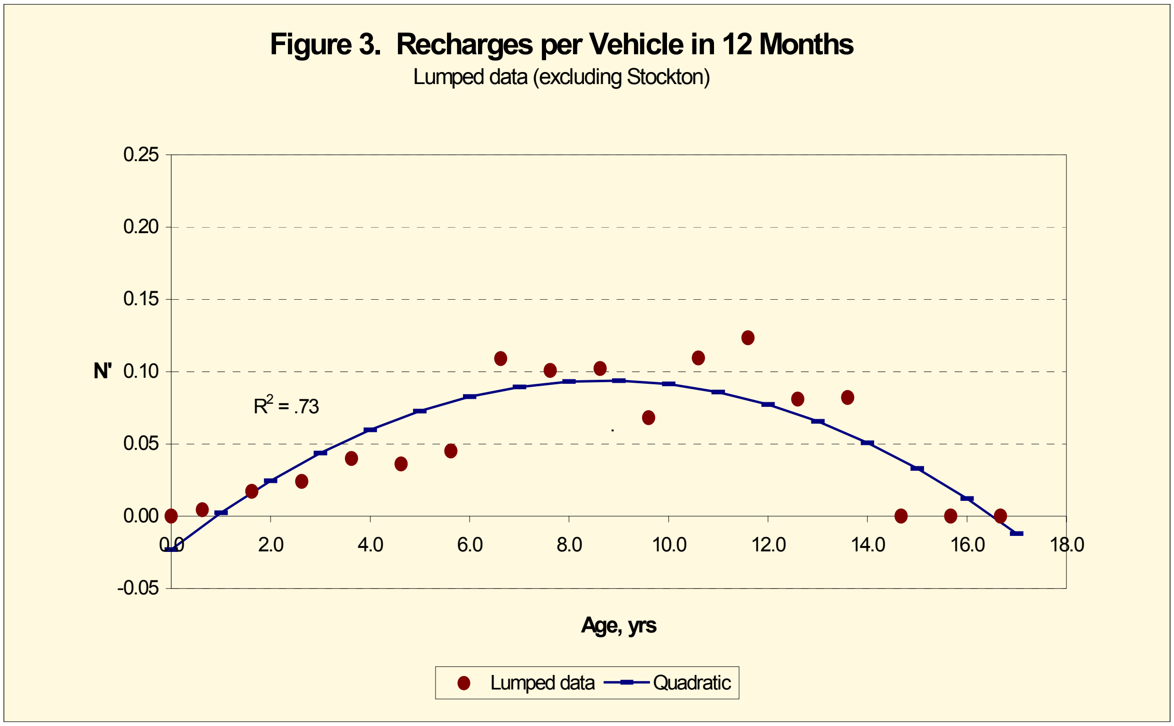
MY	Age	Re-charges	Fleet Vehicles	**N'**	Est'd Error*
1985	17.7	1	30	0.033	0.033
1986	16.7	0	31	0.000	0.000
1987	15.7	0	22	0.000	0.000
1988	14.7	0	45	0.000	0.000
1989	13.6	10	122	0.082	0.026
1990	12.6	6	74	0.081	0.033
1991	11.6	18	146	0.123	0.029
1992	10.6	15	137	0.109	0.028
1993	9.6	12	176	0.068	0.020
1994	8.6	28	274	0.102	0.019
1995	7.6	100	991	0.101	0.010
1996	6.6	76	698	0.109	0.012
1997	5.6	59	1308	0.045	0.006
1998	4.6	60	1662	0.036	0.005
1999	3.6	58	1453	0.040	0.005
2000	2.6	42	1742	0.024	0.004
2001	1.6	31	1807	0.017	0.003
2002	0.6	6	1343	0.004	0.002
2003	0.0	0	521	0.000	0.000
	All veh:	522	12,582		

* [N' * (1-N' / (# vehicles)] ^.5 (binomial variance

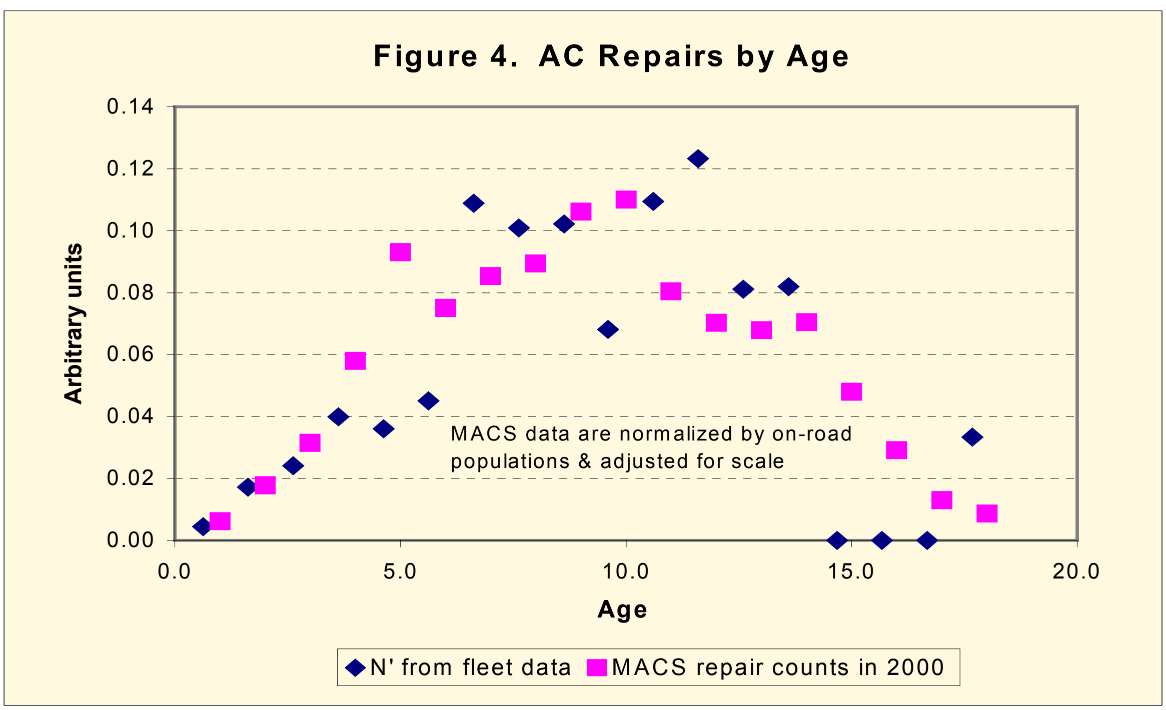
Figure 3 shows the annual frequencies by age for all the data (except Stockton) lumped together (data from Table 2. j). (The quadratic fit is discussed later.) N' peaks at about 10 years of age. There are four possible reasons for the peak:

1. After a decade, most parts susceptible to leakage have been replaced, so that the future incidence of leakage is reduced.
2. For old vehicles, it is often not worthwhile for fleets to recharge AC systems.
3. Converted systems (~1993 and earlier vehicles in the data) leak less than do original HFC-134a systems.
4. For model years older than1994, the data reflect an increasing number of Freon systems in the fleets, so that the ratio of HFC-134a recharge events to the population in the MY becomes increasingly biased low.

Reasons 3 and 4 imply bias in the data.



To test the reality of the results in Figure 3, we compared them to the relative frequencies of AC repairs of all kinds vs. age, regardless of refrigerant, in the 2000 MACS survey results [10]. The comparison is in Figure 4. The relative frequencies in the MACS data have been adjusted to account for the declining model-year populations for increasing ages of vehicle (per EMFAC). It appears that after a certain age of vehicle--about 10 years in the MACS data--privately-owned vehicles receive fewer repairs per capita than they do in the earlier ages. This observation tends to corroborate the fleet data as reflecting real-world behavior. That is, potential reasons 3 and 4 do not appear to be the cause of the peak in N'.



Having accepted the decline in the plot in Figure 3 as genuine, staff performed a least-squares quadratic regression of the data from age 0 to age 16.7. The regression curve is shown on Figure 3. Table 3 shows the predicted values of N' for ages 1 to 16 years. The sum of the 16 age-specific values is 0.978. This is the lifetime number of recharges estimated for the fleet vehicles in this analysis.

Table 3. N′ Predicted by Regression on Combined Fleet Data

Age	N'	Sum (N')	Age	N'	Sum (N')
1	.002	.002	9	.094	.562
2	.025	.027	10	.091	.653
3	.044	.070	11	.086	.739
4	.060	.130	12	.077	.817
5	.073	.203	13	.066	.882
6	.083	.286	14	.051	.933
7	.094	.375	15	.033	.966
8	.091	.468	**16**	.012	**.978**

<u>Estimating Other Model Parameters</u>

1. "C" and "f". The staff has estimated the average capacity of HFC-134a systems from the amounts of refrigerant added to evacuated systems as reported by MACS from its 2000 and 2003 surveys and by nine fleets that serviced HFC-134a vehicles. Usable data were provided for 288 vehicles.[8] The staff excluded 39 vehicles for which the amounts added differed substantially from published data [4] on the system capacities, or which were identifiable as not OEM HFC-134a vehicles, or for which the amounts evacuated exceeded the amounts recharged. Table 4 summarizes the statistics. We are using the mean of all 288 data, 951 grams, for the factor "C" in the model.

[8] The data are from records kept by the sources. The ARB staff have not reviewed the operations that produced the data for conformity to industry standards as set forth by the Society of Automotive Engineers (procedures J1732, J2209, and J2211). The adequacy of those procedures to estimate "f" has been questioned [6].

Table 4. Amounts of HFC-134a Charged to LDVs and MDVs

Source	No. Data	Mean Charge (grams)	Std. Dev.
Fresno Co.	18	888	228
City of Los Angeles	18	934	202
City of Modesto	6	683	508
Orange Co.	10	1107	293
Riverside Co.	54	1013	276
Sacramento Co.	61	860	201
San Joaquin co.	7	991	377
San Mateo Co.	4	1134	227
Verizon	49	881	180
MACS 2000 survey*	61	1013	279
Overall (all data)	288	951	254

* various U.S. locales

The same sources also reported the amounts of HFC-134a evacuated before service. The difference between the amount charged and the amount evacuated, divided by the amount charged, is the factor "f" in the model. Table 5 summarizes the "f" data for vehicles of MY 1993 and later. We are using the mean of all data, 0.52, for "f".

Table 5. Empty Fractions of Systems in Serviced Vehicles

Source	No. Data	Mean "f"	Std. Dev.
Fresno Co.	18	.47	.23
City of Los Angeles	18	.75	.32
City of Modesto	6	.66	.35
Orange Co.	10	.73	.36
Riverside Co	54	.41	.34
Sacramento Co.	61	.64	.31
San Joaquin co.	7	.68	.21
San Mateo	4	.63	.37
Verizon	49	.59	.33
MACS 2000 survey*	61	.34	.30
Overall (all data)	288	.52	.35

* various U.S. locales

2. "g". Data from European studies, from a dismantler in California, and from surveys of members of a dismantlers' trade organization in California indicate that the average HFC-134a vehicle reaching the dismantling yard has a residual charge of about 17% of its capacity. (See Section D, "Information on HFC-134a Recovery from

Dismantled Vehicles".) Federal regulations require the dismantlers to recover refrigerant. The staff's contacts with dismantlers indicates that some recovery does occur. However, the available information does not support an assumption of industry-wide compliance. We assume that 50% of the available HFC-134a is recovered, so that g = 0.085.

C. Surveys of Vehicle Owners

We have made an alternative estimate of N based on information from individual vehicle owners about the cumulative recharges to their vehicles. The information was obtained from surveys conducted among employees of Cal/EPA and U.S. EPA.

Cal/EPA Employee Survey

All employees of the California Environmental Protection Agency were invited by e-mail to return an intranet form if they were *original* owners of (1) 1995 or later MY vehicles or (2) vehicles of earlier MYs if the respondents were certain those vehicles were originally equipped with HFC-134a systems. 678 valid responses were received.

Respondents were asked to report:

- the make, model, and model year
- whether or not the AC on the vehicle had ever ceased performing adequately
- the number of professional AC repairs the vehicle had received over its life
- the number of top-offs in addition to the reported AC repairs

The staff tallied the reported AC repairs and the top-offs as re-charging events. In some cases, the respondents provided additional information about the repairs that indicated that the repairs did not involve parts of the AC systems that could leak. These events were not included in the tallies. However, most respondents did not provide the additional information, so the tally of service events (but not top-offs) may be biased high as a count of recharges.

In addition, several respondents reported cessation of performance but no repairs or top-offs. We tallied these as equivalent to service events. That is, we assumed that a recharge was warranted (because leakage had occurred) even if it was not done. These events are 17% of all the total events tallied among all the responses, but they account for only 6% of the events among the 1993 and 1994 vehicles, which provide the "bottom line" of the analysis.

Table 6 shows the tallies by model year. The frequency for a model year is the number of events divided by the number of survey vehicles. It is the mean cumulative number of events per vehicle to date for that model year. The "adjustments" are reductions of the number of events for one brand of vehicle that had very high frequencies. The brand was over-represented in the survey sample compared to its on-road population--2% of sample vs. 1% of population--according to the staff's analysis of a 500,000-

vehicle random sample from DMV files (See Doc F].). The actual number of events for this brand were reduced by half. (No other adjustments were made.)

Figure 5 plots the frequencies of repairs, top-offs, and cessations of operation without repairs, and the totals. Figure 6 repeats the totals of the three frequency elements and shows error bars of $\pm$ 2 standard errors and the numbers of vehicles providing the data.

Through the 1995 model year (age 8), the mean cumulative recharges has reached about 0.4 per vehicle. For the 1993 and 1994 model years, it jumps to about 1.1. However, the uncertainty on that value is quite large. Because of the instruction to respond for 1993 and 1994 vehicles only if they were OEM HFC-134a vehicles, the numbers of responses for those years were too small to provide good precision.

Table 6. Responses for 678 Vehicles to Cal/EPA Survey on Cumulative Events

	Repairs per vehicle:						Top-offs per vehicle:						Vehicle ceased oper. w/o repair		Total Events^	Adjust-ment	**Total Freq.****	Std. Error^^
	0	1	2	3	4		0	1	2	3	4							
MY	Vehicle Counts					Freq.*	Vehicle Counts					Freq.*	Count	Freq.*				
1993	8	1	1	1	1	0.83	9	2	1	0	0	0.33	1	0.08	15	-2	**1.08**	0.30
1994	13	2	1	2	0	0.56	13	0	4	1	0	0.61	1	0.06	22	-2	**1.11**	0.25
1995	46	5	2	0	1	0.24	51	0	3	0	0	0.11	2	0.04	21	-2	**0.35**	0.08
1996	47	13	1	1	0	0.29	56	3	2	1	0	0.16	3	0.05	31	-2	**0.47**	0.09
1997	66	4	0	0	0	0.06	69	1	0	0	0	0.01	1	0.01	6		**0.09**	0.03
1998	72	4	0	0	0	0.05	73	3	0	0	0	0.04	2	0.03	9		**0.12**	0.04
1999	92	1	0	1	0	0.04	88	4	2	0	0	0.09	3	0.03	15		**0.16**	0.04
2000	83	2	0	0	0	0.02	85	0	0	0	0	0.00	4	0.05	6		**0.07**	0.03
2001	84	1	1	0	0	0.03	82	3	1	0	0	0.06	1	0.01	9		**0.10**	0.03
2002	73	1	0	0	0	0.01	73	1	0	0	0	0.01	4	0.05	6		**0.08**	0.03
2003	46	1	0	0	0	0.02	47	0	0	0	0	0.00	0	0.00	1		**0.02**	0.02
Total	630	35	6	5	2	0.10	646	17	13	2	0	0.07	22	0.03	141	-8	**0.196**	0.02

* Freq = events / # vehicles
(events = sum of [Counts * repairs or top-offs /vehicle])

^ sum of events of all types
** (Total Events + adjustment) / # vehicles

^^ Standard error estimates are calculated assuming that the total events follow the Poisson distribution. Therefore, the variance of the total events equals the expectation value for the total events, which is approximated by the observed number of events (e.g., 15 for MY 1993). The variance of the "frequency" (as the term is used here) equals (variance of total events) / (# vehicles^2), which equals Freq / # vehicles. The standard error is the square root of (Freq / # vehicles) .

Figure 5. Lifetime Events per Vehicle
Cal/EPA Survey

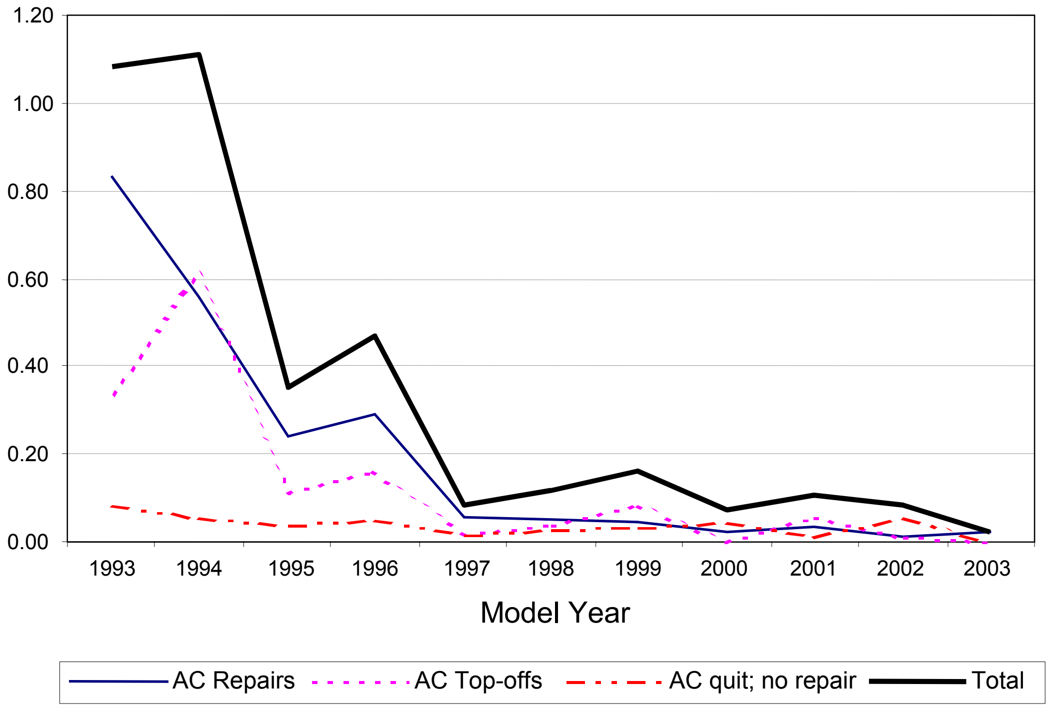
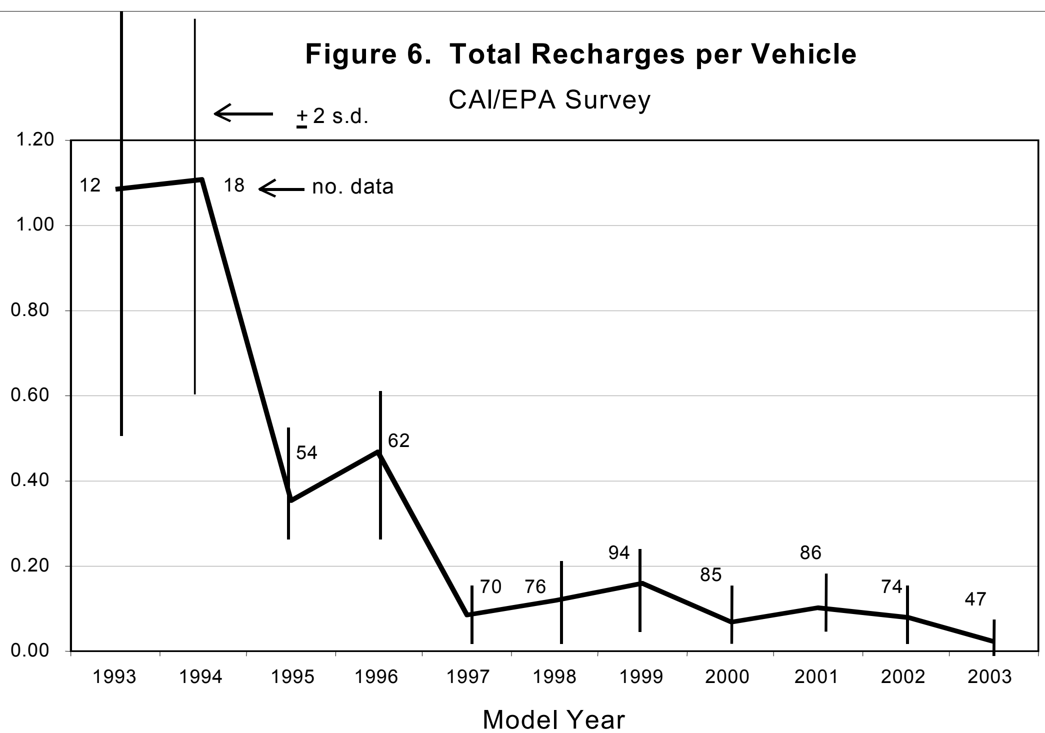


Figure 6. Total Recharges per Vehicle
CAI/EPA Survey



Survey of U.S. EPA Employees

Nearly the same survey was conducted on our behalf among employees of some offices of the U.S. EPA in Washington, DC. The only difference from the Cal/EPA survey is that owners of 1993 and 1994 vehicles were asked to respond regardless of the type of AC system in their vehicles.

Only 288 valid responses were received. However, the numbers for 1993 and 1994 vehicles--12 and 22--at least equaled the numbers for those model years in the Cal/EPA survey. When data from the two surveys are combined, the doubling of the counts reduces by 30% the uncertainty in N for those model years in the Cal/EPA survey. Table 7 shows the tallies and frequencies from the U.S. EPA survey.

Figure 7 shows the frequencies. Figure 8 compares the estimates of total recharges from the two surveys. Agreement is good.

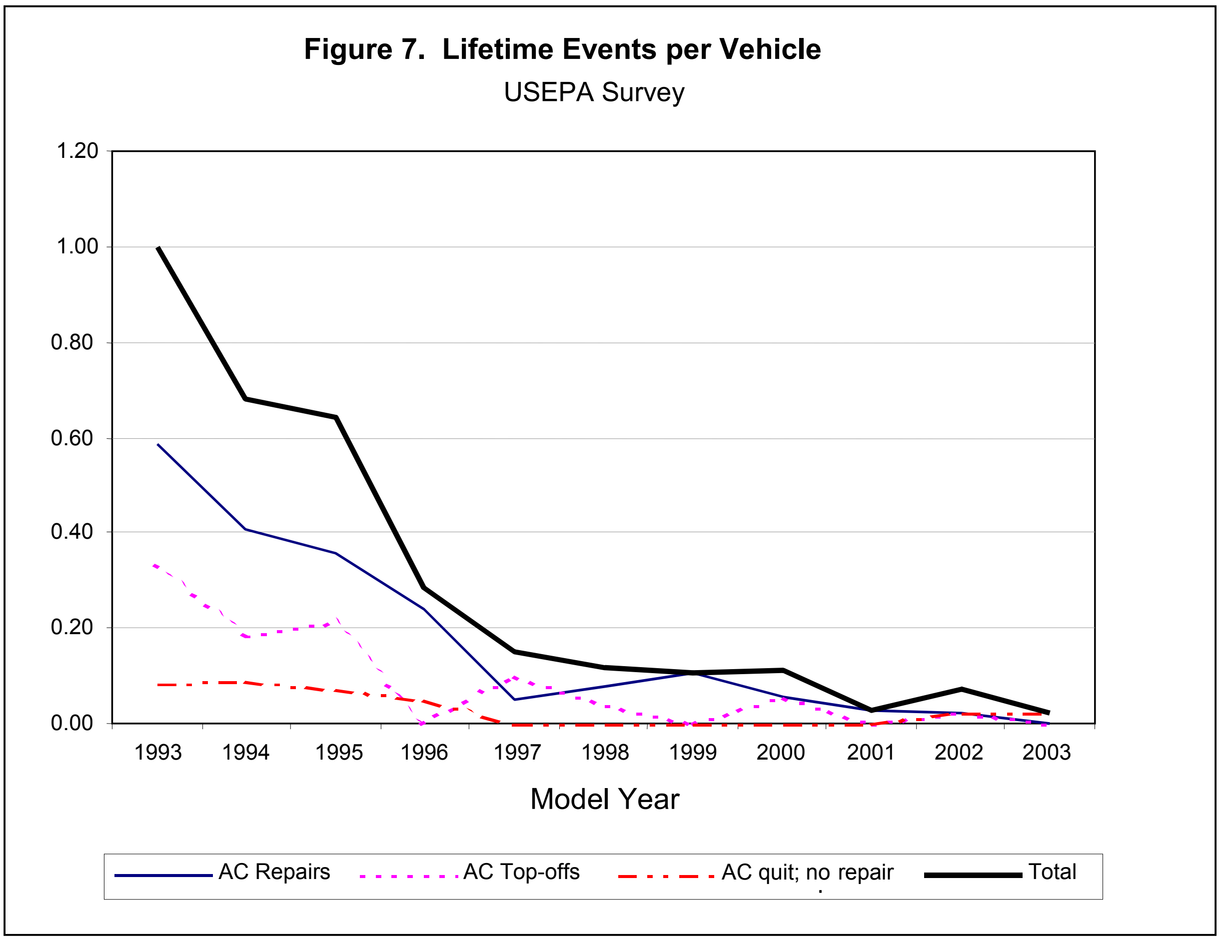


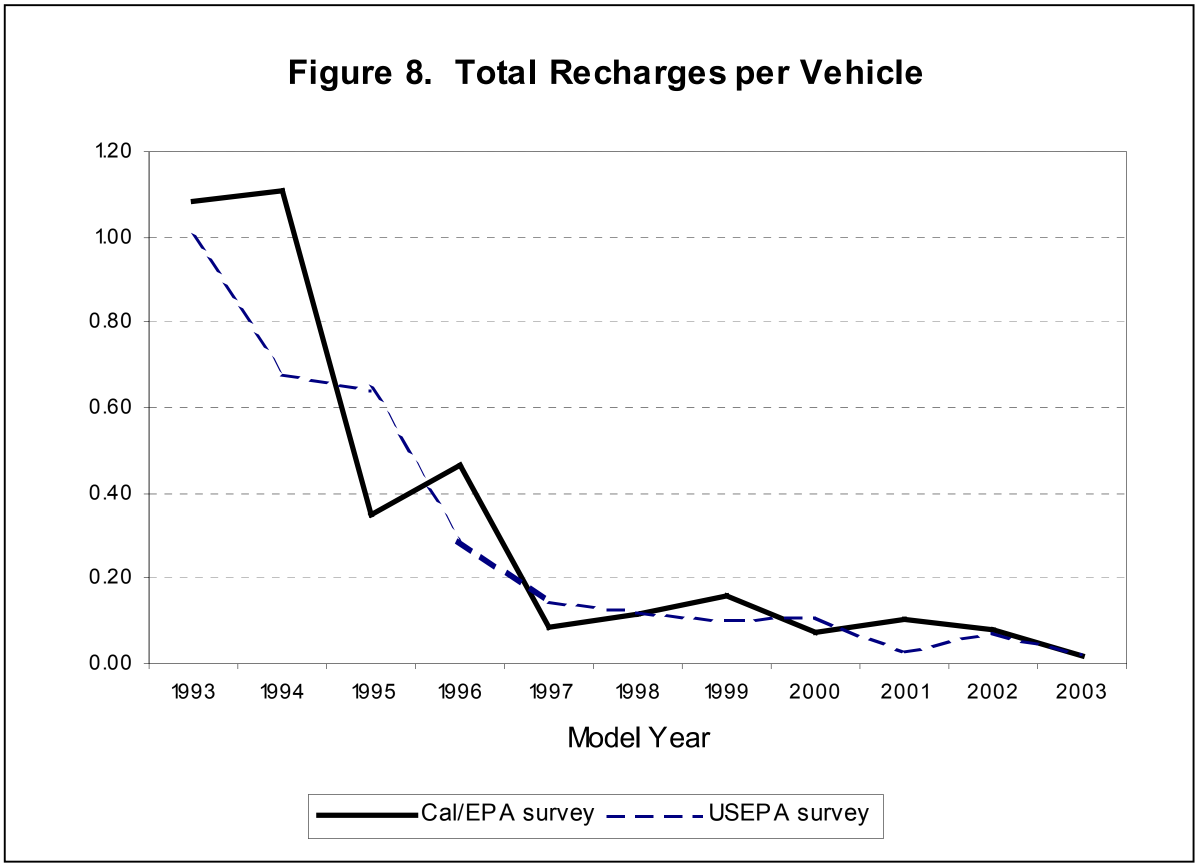
Table 7. Responses for 288 Vehicles to U.S. EPA Survey on Cumulative Events

	Repairs per vehicle: Vehicle Counts						Top-offs per vehicle: Vehicle Counts						Vehicle ceased oper. w/o repair		Total Events^	Adjust-ment	**Total Freq.****	Std. Error^^
MY	0	1	2	3	4	Freq.*	0	1	2	3	4	Freq.*	Count	Freq.*				
1993	7	3	2	0	0	0.58	9	2	1	0	0	0.33	1	0.08	12		1.00	0.29
1994	17	2	2	1	0	0.41	20	1	0	1	0	0.18	2	0.09	15		0.68	0.18
1995	11	2	0	1	0	0.36	12	1	1	0	0	0.21	1	0.07	9		0.64	0.21
1996	17	3	1	0	0	0.24	21	0	0	0	0	0.00	1	0.05	6		0.29	0.12
1997	19	1	0	0	0	0.05	18	2	0	0	0	0.10	0	0.00	3		0.15	0.09
1998	24	0	1	0	0	0.08	24	1	0	0	0	0.04	0	0.00	3		0.12	0.07
1999	18	0	1	0	0	0.11	19	0	0	0	0	0.00	0	0.00	2		0.11	0.07
2000	35	0	1	0	0	0.06	34	2	0	0	0	0.06	0	0.00	4		0.11	0.06
2001	35	1	0	0	0	0.03	36	0	0	0	0	0.00	0	0.00	1		0.03	0.03
2002	40	1	0	0	0	0.02	40	1	0	0	0	0.02	1	0.02	3		0.07	0.04
2003	42	0	0	0	0	0.00	42	0	0	0	0	0.00	1	0.02	1		0.02	0.02
Total	265	13	8	2	0	0.12	275	10	2	1	0	0.06	7	0.02	59	0	0.205	0.03

* Freq = events / # vehicles
(events = sum of [Counts * # per vehicle])

^ sum of events of all types
** (Total Events - adjustment) / # vehicles

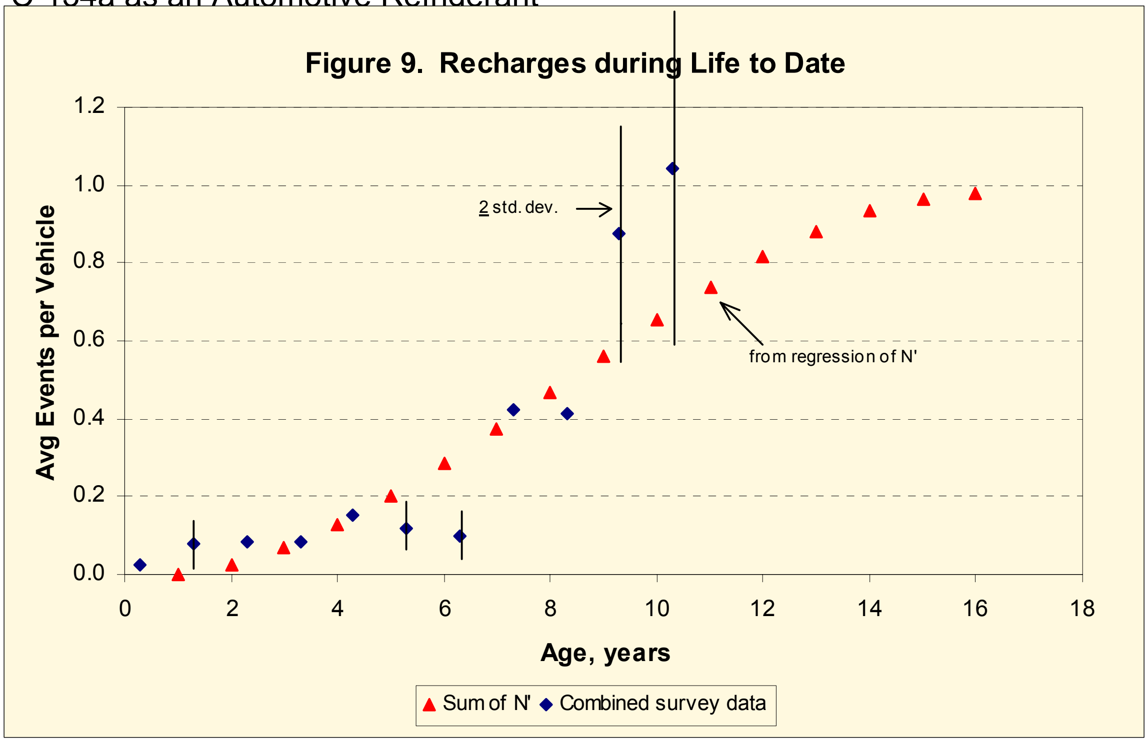
^^ Standard error estimates are calculated assuming that the total events follow the Poisson distribution. Therefore, the variance of the total events equals the expectation value for the total events, which is approximated by the observed number of events (e.g., 15 for MY 1993). The variance of the "frequency" (as the term is used here) equals (variance of total events) / (# vehicles^2), which equals Freq / # vehicles. The standard error is the square root of (Freq / # vehicles) .



Survey Results vs. Results from Fleet Data Analysis

Figure 9 shows the results of combining the data from the the two surveys, with error bars, and superimposes the running sum of the 16 N' values from the fleet analysis. The combined survey results appear to be consistent with the fleet analysis except for the oldest survey vehicles, for which the numbers of data are still fairly small and the uncertainty is large.

From the two results, the staff has arrived at 1.0 as the estimate for N.



D. Annual Emissions, ca. 2003

We have estimated by two methods the annual vehicular emissions of HFC-134a in California, circa 2003. Both methods involve data related to the recharging of refrigerant to replenish leakage. Such data carry temporal information about the leakage that occurs before the recharges. However, according to our lifetime emission model, only about a third of the average total lifetime emissions are reflected by recharging. Therefore, our data provide temporal information for only about a third of the total leakage from an on-road population. Thus, to place *total* emissions on an annual basis, we need to annualize the leakage that has not been replenished; that is leakage from vehicles' final charges and leakage from new vehicles that have not yet needed recharges. For that, we have no data, and we have relied on an assumption described below.

Using N' Values

This approach involves multiplying each N' value from the fleet-data analysis by the fraction of the on-road population in the corresponding model year and summing the products. The sum of products measures total recharges in 2003 per in-use vehicle.

Table 8 contains the analysis. The product sum is from age 1 (MY 2003) down to the last age (16 years, MY=1988) when the number of recharges per model year remains positive according to the regression developed in the fleet-data analysis. This represents the hypothetical case that all vehicles on the road in 2003 use HFC-134a, (which will be virtually the true in 2009, although the on-road fractions by age may differ by then).

Table 8. Estimating 2003 Recharges with N' Values

Age	MY	Fraction of Fleet*	N' (recharges/yr/veh)
1	2003	0.066	.002
2	2002	0.065	.025
3	2001	0.062	.044
4	2000	0.062	.060
5	1999	0.063	.073
6	1998	0.058	.083
7	1997	0.058	.094
8	1996	0.051	.091
9	1995	0.057	.094
10	1994	0.049	.091
11	1993	0.045	.086
12	1992	0.039	.077
13	1991	0.043	.066
14	1990	0.040	.051
15	1989	0.040	.033
16	1988	0.034	.012
Product sum^, 1 to 16 years:			.051

* Per EMFAC, vehicles with GVWR < 8500 lbs
^ sum of (fraction of fleet * N')

This is an inexact approach whose error cannot be analyzed. The error results from the discrepancy between the year of leakage and the year of recharging. (See Section B-1.) Like the lifetime emission model, it contains confounded effects of model year and age of vehicle, so that there is no mathematical basis to adjust the results to become specific to 2009.

When the weighted sum in Table 8 is multiplied by 0.52 * 951 grams per recharge (as in the lifetime emission calculation), the result estimates leakage that has been replenished during servicing. There must also be an accounting for leakage that occurs after the final charge of the system or that has not yet been reflected by recharging young vehicles. According to the lifetime emission model, all material charged to the vehicle except 0.085 * C is emitted, whether by leakage or release at scrapping. However, there is no information in the recharge data about the timing of those emissions. For this accounting, we have assigned 1/16 of the partially recovered final charge (0.915 * 951 grams) to each year, which allocates the emissions from the unrecovered charge uniformly over the average vehicular life.

Then, the emission estimate for the average light-duty vehicle in 2003 (as if all vehicles used HFC-134a) is:

951 gram capacity * [0.051 recharges * 0.52 capacity fraction per recharge + 0.0625 * .915]

= 80 grams / HFC-134a vehicle / year

Using HFC-134a Consumption Data

Nine fleets, shown in Table 9, have provided records for periods during the summer and fall of 2003. As in the analysis for N', the vehicles in Table 9 are nearly, but possibly not identically, solely HFC-134a vehicles. Note that the averages values of model year are close to the estimate from EMFAC for the average model year on the road among vehicles sold with HFC-134a vehicles, 1998.7.

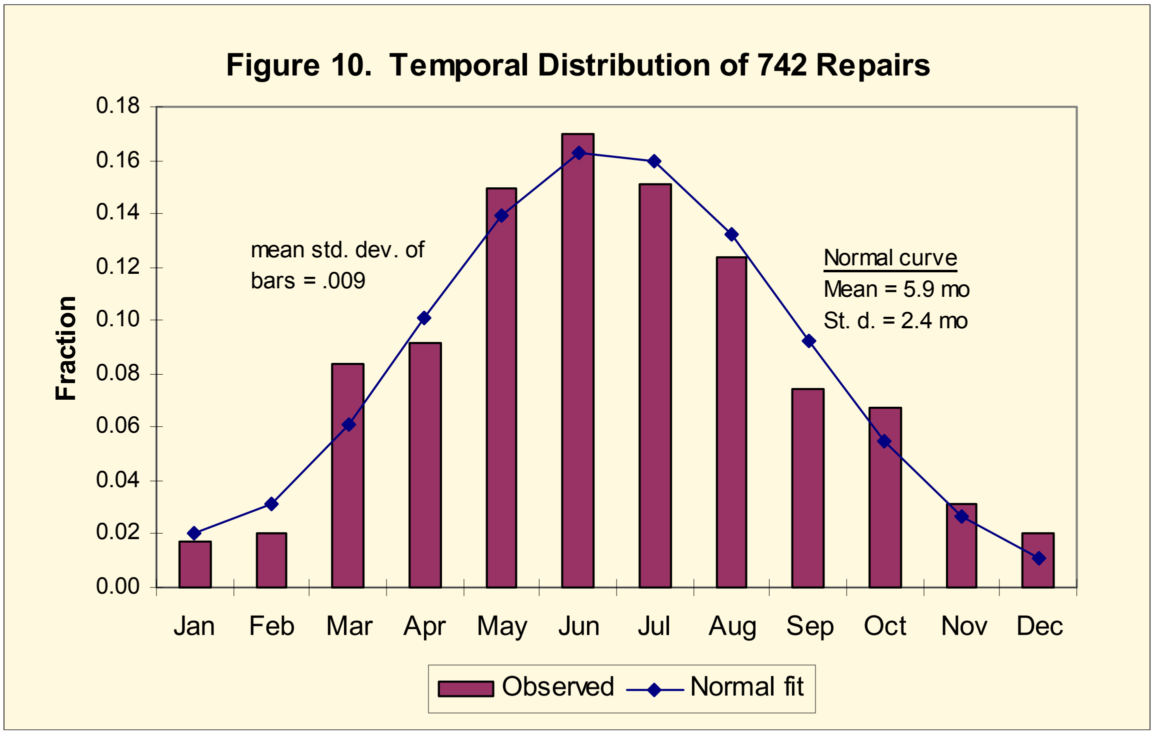
Table 9. Vehicles and Use of HFC-134a by Fleets, Summer 2003

Fleet	Location	Data Period	HFC-134a Fleet Vehicles			Kg HFC-134a used in period
			count	avg MY*	% trucks^	
City of LA	Los Angeles	5/12 - 6/27	3485	1998.4	55	17.1
Verizon	various	5/1 - 8/1	2219	1997.7	70	27.1
Riverside Co.-1	Riverside	5/28 - 9/2	1765	1999.2	46	13.5
San Joaquin Co.	~Stockton	5/23 - 7/2	1048	1998.3	51	9.5
Fresno Co.	~Fresno	6/5 - 8/5	882	1999.1	46	11.4
Riverside Co.-2	Indio	5/28 - 9/2	454	1999.3	33	3.5
City of Modesto	Modesto	6/3 - 7/30	443	1999.1	57	5.5
Riverside Co.-3	Hemet	5/28 - 9/2	307	1999.0	35	3.6
Riverside Co.-4	Banning	5/28 - 9/2	153	1997.8	52	2.9

* In Calif. on-road fleet (gross vehicle weight rating <8500 lbs), avg MY = 1998.7 for MY>1993

^ pickups, vans, and SUVs

It is necessary to extrapolate the amounts of HFC-134a used during the data periods to annual (12-month amounts). Staff has done this by dividing the amount per vehicle, shown in the right-most column of Table 9, by the fraction of the total area under the curve in Figure 10 that corresponds to the data period for a particular fleet. Figure 10 was generated from dated repair records from nine fleets (Modesto, Stanislaus Co., Riverside Co., Verizon, CSAA, San Joaquin Co., Kern Co., San Bernadino Co., and Fresno) It shows the distribution by month of 742 dated AC service events for HFC-134a vehicles. It is fit well by a normal distribution curve with mean month 5.9 months (end of June) and standard deviation 2.4 months.



The right-most column of Table 10 shows the results of the extrapolations. These emission factors have no apparent relationship to the average model years or % trucks that are shown in Table 9.

Table 10. Emission Factors from Fleet Data, Summer 2003

Fleet	Use / vehicle in data period (kg/veh)	Fraction of area under curve in Fig. 8 correspond-ing to data period	Annual use / vehicle * (kg/veh/year)
City of LA	.0049	.234	.020
Verizon	.0123	.460	.025
Riverside Co.-1	.0076	.480	.015
San Joaquin Co.	.0092	.239	.035
Fresno Co.	.0129	.339	.035
Riverside Co.-2	.0078	.480	.015
City of Modesto	.0124	.309	.037
Riverside Co.-3	.0117	.480	.023
Riverside Co.-4	.0190	.480	.037

* column 1 / column 2

The emission factors in Table 10 have been averaged with two sets of weights: 1) the number of vehicles in the fleet and 2) the number of vehicles x area fraction (3rdcolumn in Table 10). The respective averages are 23 and 24 grams/vehicle/year.

When the allowance for emissions related to the final charge (951 kg * 915 /16, described in the preceding section) is included, the mean of these two values becomes 78 grams/vehicle/ year. This is close to the estimate based on the N', 80 grams/veh/ year. We are using the common value of the two results at one significant figure, 80 grams/veh/year.

Comparisons to Other Results

Several comparisons to other results can be made for the 80-gram estimate of the 2003 annual emissions among HFC-134a vehicles:

- The European Commission study in 2003 [1] found an average of 7% loss of charge per year among 276 new vehicles. Applied to the mean capacity estimate of 951 grams, that is equivalent to 67 grams/year/vehicle. Since the 80-gram estimate includes emissions from vehicles up to the age (~9 years) when AC service peaks and end-of-life emissions, but the EC study included neither, it is appropriate that our result exceeds the result based on the EU study.
- The lifetime model result from the fleet-data analysis is 1.36 kg over 16 years, averaging 85 grams/year of life. The in-use fleet is composed of model-year populations that decline with age, including the ages when N' peaks. Thus, it is appropriate that the emission rate averaged over in-use vehicles (80 grams/yr) is somewhat less than the annual average for a 16-year lifetime.
- In diurnal SHED testing with the engine (and AC) not operating and the vehicles cold, Ford [3] measured an average of .07 gram/day per vehicle among 28 light-duty, in-use vehicles of recent vintages. At a constant leak rate, this is equivalent to 26 grams/year. When a vehicle is hot and the AC is in use, the pressures in the system are much greater than at the maximum of 96 ^{o}F in a diurnal SHED test. Presumably, leakage increases with pressure. For this effect and the inclusion of scrapping loss, it is appropriate that that our result substantially exceeds the rate measured by Ford.
- The U.S. EPA [5] has made annual estimates of HFC emissions from mobile air conditioners from 1995 to 2001. The estimates extrapolate to about 2.1 x 10^{10} grams in 2003. The estimate includes leakage and servicing losses (which are not shown independently), and it contains an assumption of recovery of the HFC-134a when vehicles are dismantled. (The cited source does not quantify that assumption.) The corresponding number of vehicles is not stated but (presumably) includes all on-road vehicle classes. A reasonable assumption based on the California vehicle population is 150 million total vehicles using HFC-134a.[9] If so, the emissions per vehicle are

about 140 grams per year. Since all the parameters of the model are proprietary and confidential, we cannot analyze the difference from the staff's estimate of 80 grams/year/vehicle. However, the excess emissions estimated by U.S. EPA may include HFC-134a used to refill Freon systems or wasted during do-it-yourself repairs. (See "Use of HFCs in Refrigeration; Emission Sources Other Than Vehicular Leakage".)

- The Swiss Federal Laboratories for Materials Testing and Research [7] estimated the average emission rate among vehicles travelling in the Gubrist Tunnel in Switzerland in the fall of 2002 by measuring the mass rate of outflow of HFC-134a from the tunnel. Their result is 14 mg/hr/HFC-134a vehicle, which is equivalent to 120 grams/year. It is appropriate this exceeds our result, which is an average over all hours of a year. Presumably, the fraction of AC systems in operation in the tunnel was greater than the average fraction of a year that vehicles' ACs are used. Considering the days and times of vehicle non-use and the cold seasons of a year, that latter fraction in California must be less than ten percent. Presumably, leakage is greater when AC systems are in use because of the much greater pressures.

- A Dutch study reviewed in an EC report [8] estimated the annual leakage rate from private cars at 9% of capacity, while the 80-gram estimate is equivalent to 8%.

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2. Lindberg, Vern; "Uncertainties and Error Propagation--Part I of a manual on Uncertainties, Graphing, and the Vernier Caliper", http://www.rit.edu/~vwlsps/uncertainties/Uncertaintiespart2.html, July 1, 2000.

3. Siegl, W.O. and Wallington, T.J.; "R134a Emissions from Vehicles", Environ. Sci. Technol., 36, (4), 561-566, 2002.

4. "Air Conditioning System Refrigerant Capacities", by Motor Information Systems, a division of Hearst Business Publishing, Inc., 2003.

5. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2001, Final Version EPA 430-R-03-004, April 2003.

6. Memo from Ward Atkinson to Interior Climate Control Committee and Working Groups (of SAE), December 3, 2003.

[9] 13 million Calif. L&MDVs (MY >1993) * ~1.15 total vehicle/LDV (from Emfac) * ~10:1 US vehicles/Calif vehicle = 150 million vehicles in US

7. Stemmler, Konrad, internal report of EMPA, Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Switzerland.
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11. Baker, James A., Delphi; Mobile Air Conditioning System Refrigerant Emissions Measurement”, Mobile Air Conditioning Summit, Washington DC, April 2004.

12. Matsuno, Takayoshi, et al.; “JAMA’s Voluntary Action Plan to Reduce HFC-134a Emissions”, Mobile Air Conditioning Summit, Washington DC, April 2004.

SECTION B-1

Theory of Analysis of Annual Recharging Frequencies

Estimating *Lifetime* Leakage from Annual Recharge Frequencies

Considering just a set of n_r vehicles that receive HFC-134a recharges over a year, the cumulative amount of HFC-134a they receive is given by

$$U\,(\text{mass/yr}) = \sum_{v=1}^{n_r} C_v * f_v * \mathbf{1}\ \text{recharge/yr/serviced vehicle}$$

where C is the system capacity and f is the fraction empty.

$$\text{Thus,}\quad U/n_r = \text{Average of}\,[C_v * f_v * \mathbf{1}\ \text{recharge/yr/serviced vehicle}]$$
$$\approx \overline{C} * \overline{f} * \mathbf{1}\ \text{recharge/yr/serviced vehicle}$$

where the bars indicate average over vehicles. This is the just the average amount charged to the n_r vehicles that are serviced in a year, replacing refrigerant leaked prior to the recharges.

For a fleet, the n_r serviced vehicles are a subset of a specific (fixed) population of vehicles, n_{pop}, that could have received recharges from the same source in the same year (although most did not). Multiplying the above equation by n_r/n_{pop} (which is N') yields

$$U/n_{pop} = \text{leakage}\ \textit{replaced}\ \text{during the year, averaged over}\ \underline{\text{all}}\ \text{vehicles in fleet}$$
$$\approx n_r/n_{pop}\ [\text{recharges/yr/fleet vehicle}] * \overline{C} * \overline{f}$$
$$\approx N' * \overline{C} * \overline{f} \qquad [A]$$

This use (replacement) rate over a year equals leakage loss from the fleet over *some* period. That period is not necessarily one year; the replaced refrigerant could have leaked over any period prior to recharging. However, by mass balance, the sum of sequential annual values of U/n_{pop} for the n_{pop} vehicles over their lifetimes must equal the total replaced leakage[10] from those vehicles over all periods before their final recharges.[11]

The average vehicular lifetime in California, consistent with statistics in EMFAC, is 16 years. If U/n_{pop} were observed annually for a fixed set of vehicles that all “lived” 16 years, the sum of the 16 consecutive values of would be proportional to lifetime emissions per vehicle for those vehicles. (We assume that observations over a period equal to the

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[10] Actually, the use of HFC-134a includes whatever wastage occurs during servicing. However, for commercial or fleet service operations, we think that wastage is nil.

[11] Leakage between the last recharge and scrapping is not replaced and is **not** reflected by use of HFC-134a for recharging. Such leakage is accounted by the term 1 - g in the lifetime emission model.

average vehicular lifetime would be equivalent to the average observation over many individual vehicular lives.)

Rather than observing a set of vehicles for 16 years, we have calculated 16 independent model-year-specific values of N' during one year of recharge counting. Thus, we have simultaneous one-year "snapshots" (taken in 2003) for 16 separate model years. *We assume that the sum of those model-year values is proportional to lifetime of the "average" vehicle in the model-year range*, just as 16 consecutive age-specific values of N' would be for a single model year.

Note that the sum of the 16 measured values gives the value of N for a hypothetical vehicle that spent its first year as a 1987 model, its second year as a 1988 model, etc. Note also that computing N' by model year avoids the problem of vehicular attrition that would be encountered if one tried to observe recharges in a fleet over 16 calendar years.

Estimating *Annual In-use* Emissions from Recharge Frequencies

But, can the model-year-specific annual recharge frequencies (N') be used as estimators of emissions for an age group (model year) in a specific calendar year? Regarding precision, the posited answer is "yes" if enough vehicles are involved.

Since n_r and n_{pop} are integers, n_r/n_{pop} is a discrete, not continuous, variable; it is not ideal for representing a continuous process such as refrigerant leakage. AC servicing is a sporadic, discrete event for individual vehicles, having values of either 0 or 1 in a given year. The count for a single vehicle in a given year is only a very gross indicator of the annual frequency for a large population of similar vehicles. However, if n_{pop} is large enough and the actual frequency is not too small, n_r has many possible values, with a probability distribution approximated by the Poisson (continuous) distribution. That is, the observed values of n_r (and n_r/n_{pop}) should behave as continuous variables rather than "lumpy" (imprecise) variables. To meet the condition of "enough" vehicles in a MY, it is very desirable to be able to combine data from the distinct fleets.

However, with regard to accuracy, there is a problem. Clearly, not all leakage during the first year of a vehicle's life is recharged during that year. Therefore, the annual recharge frequency among one-year-old vehicles must understate annual leakage from those vehicles. During the second year, again, not all leakage is reflected by recharges, but some of the first year's leakage "missed" by the first year's recharge frequency may be reflected in the second year's recharges. As the years progress, all the early years' leakage must be reflected by recharges (unless there is no recharge, in which case the initial charge less recovery at scrapping accounts for the leakage). That is: late-year recharges tend to overstate leakage during the corresponding calendar years.

One can estimate annual emissions in a year by multiplying N's for succeeding ages (model years) by the corresponding vehicle populations by model year (as in EMFAC). However, because of the errors in equating annual recharge frequencies to annual leakage incidence, the result must contain error. If the population of vehicles were uniform by model year [12], the understatement of emissions (per vehicle) by the early-age N's would be offset by the overstatements by the late-age N's. However, the actual populations decline with age. Therefore, the integration of N' x road population contains indeterminate error.

Estimating Annual Emissions from the Annual Consumption of HFC-134a

Imagine that every model-year's vehicles behave the same, on average, with respect to the number and timing of recharges. Also, imagine that every year, a fleet drops its oldest vehicles and replaces them with the same number of new vehicles, so that its model year distribution remains constant from year to year. In that case, the expectation value for leakage occurring in the fleet would be the same year by year.

A year's leakage would not all be replaced by recharges in that year. But over time, the amount used to recharge would have to equal the amount leaked. Since there is no reason to expect the annual recharge rate to vary by year, the (uniform) expected annual recharge rate must equal the uniform expected annual leakage rate. *Thus, any year's observed recharge amount would be an unbiased estimator of the expected annual emission rate from that fleet*. This is true for any composition of the hypothetical fleet.

The fleets actually observed in 2003 are not invariant in composition over time. However, *an observation of the fraction that needed recharges in 2003 is just one of the series of observations just discussed for the hypothetically invariant fleet.* Therefore, it should be an unbiased (although probably imprecise) estimator of the annual leakage rate from that fleet *as it was composed in 2003.* (However, it would not be an unbiased estimator for another year when the composition would be different.)

[12] which is the case for the 16-year lifetime emission model

SECTION C

Analyses of the Effects of Control Measures

The net effect on lifetime emissions of a particular reduction of the slow leak rate is very complex to model because the population is composed of vehicles with widely different characteristics related to lifetime emissions. We have analyzed the effect for two special vehicles:

- a vehicle that behaves as does the “average” current vehicle represented by the lifetime emission model (described in Section B “Quantification of Vehicular HFC Emissions”), which receives one lifetime recharge; and
- a vehicle that receives no recharges

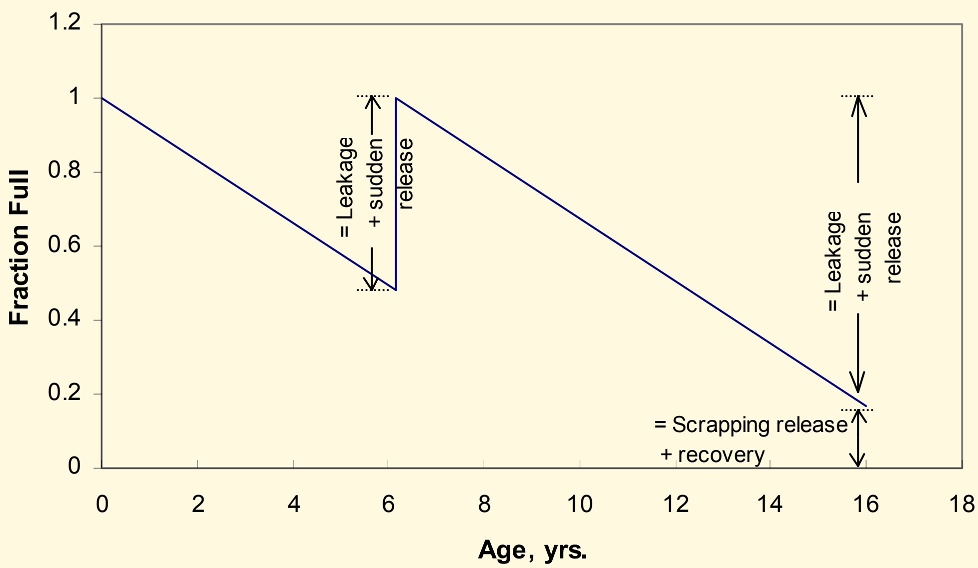
Also, we have made an estimate based on the “N’ analysis” that is presented in Section B. The three estimates follow.

Model Vehicle

Per the lifetime emission model, this vehicle receives one recharge, has a life of 16 years, receives one recharge of HFC-134a that equals 0.52 times the system capacity, and has a residual charge at age16 equal to 0.17 times the capacity. Of that residual, one-half is assumed to be recovered. The lifetime emissions are 1.43 times the system capacity. We further assume in this example that the emission rate (leakage plus sudden release) is uniform throughout the 16 years.

For these parameters, the recharge of the model vehicle necessarily occurs at age 6.16 years and the overall leak rate is .0844 capacity units per year (full = 1.0 unit). The state of charge of the system through time is shown in Figure 1.

Figure 1. State of Charge of Model Vehicle
(assuming constant leak rate)



The recharge replenishes what has been emitted up to that time--leakage plus an allowance for sudden (accidental) release. At the end of life, the residuum of 17% will be half released and half recovered, with the balance of the full charge that existed after the recharge having been emitted.

For a realistic assessment of how this picture changes with improved leak-tightness, the overall loss rate must be split into slow (leakage) and sudden (accidental release) components. The latter is not responsive to improved leak-tightness. For this, we are using the results of a study conducted by Oko-Recherche for the German Federal Environment Office.[13] Historical data on 841 vehicles serviced at 19 German auto dealerships were analyzed to estimate HFC-134a leak rates. Vehicles that had totally lost most of their refrigerant were assumed to have had sudden losses. The authors thereby estimated that, on average across the vehicles, 1.9% of design capacity was lost per year from sudden losses. This is a “soft” number because of uncertainties its derivation and its European basis. We have rounded it to 2% per year as the sudden loss rate.

If the (slow) leak rate is reduced by some degree, the slope of the fraction-full line declines and the time of the recharge moves rightward. The amount that leaks before the recharge remains the same,[14] but the amount that leaks after the recharge declines (because both the rate and duration of leakage are reduced). However, the fraction full at end of life increases, and half of the leakage that has been avoided is lost (per the assumed 50% recovery) when the residuum is released.

Figure 2 shows the state-of-charge history if the leak rate is reduced by 50%. The age of recharge has moved from 6 to 10 years, but the system is much fuller at the end of life.

Figures 3 and 4 show the emissions for the base case and the case of 50% control of slow leakage, at a constant “sudden” release rate of 2% per year. The overall reduction of emissions is 18% ({1.44 - 1.18}) / 1.44).

Table 1 shows results for several values of the control of (slow) leakage and the rate of recovery at scrapping. Figure 5 plots the overall reductions. The sensitivity of the benefit of reduced slow leakage to the rate of recovery at scrapping is easily seen. (The sudden jump in overall reduction at 81% control of slow leakage is due to the avoidance of the recharge and the attendant lower system content to be released at the end of life.)

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[13] Schwartz, Winfried, “Emissions of Refrigerant R-134a from Mobile Air Conditioning Systems”, Öko-Recherche, prepared for the German Federal Environment Office, 2001.

[14] We assume that improved leak-tightness will not affect the critical loss of charge (0.52 units) that triggers the need for a recharge.

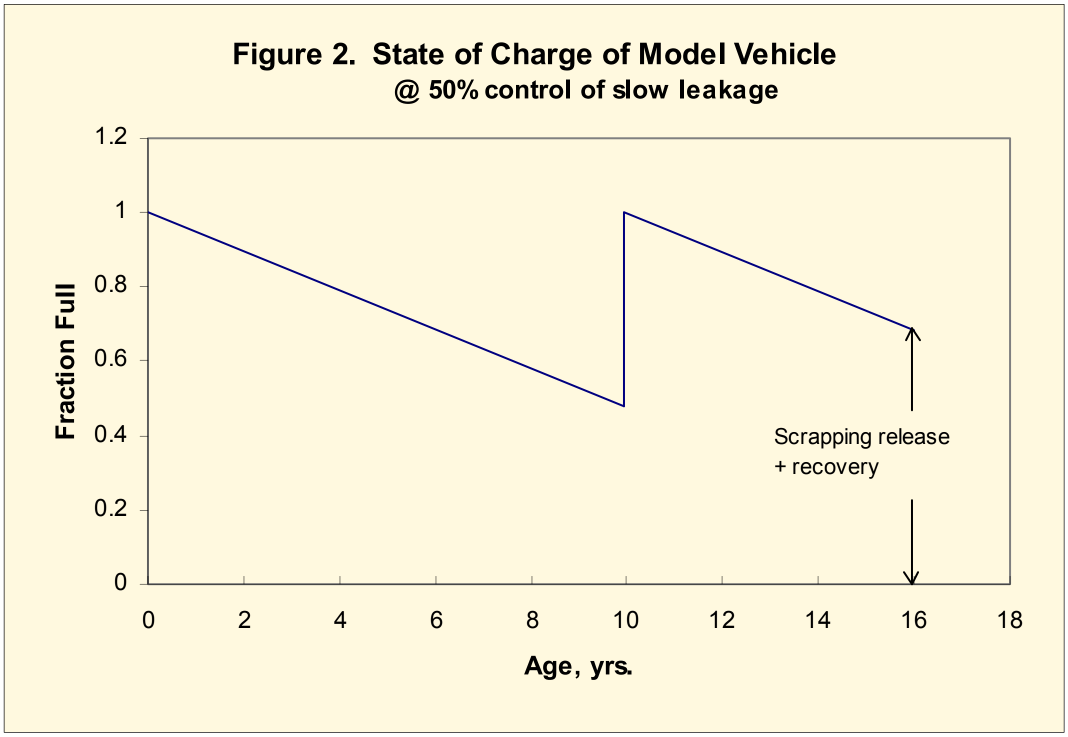


Figure 2. State of Charge of Model Vehicle
@ 50% control of slow leakage
Fraction Full
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
14
16
18
Age, yrs.
Scrapping release
+ recovery

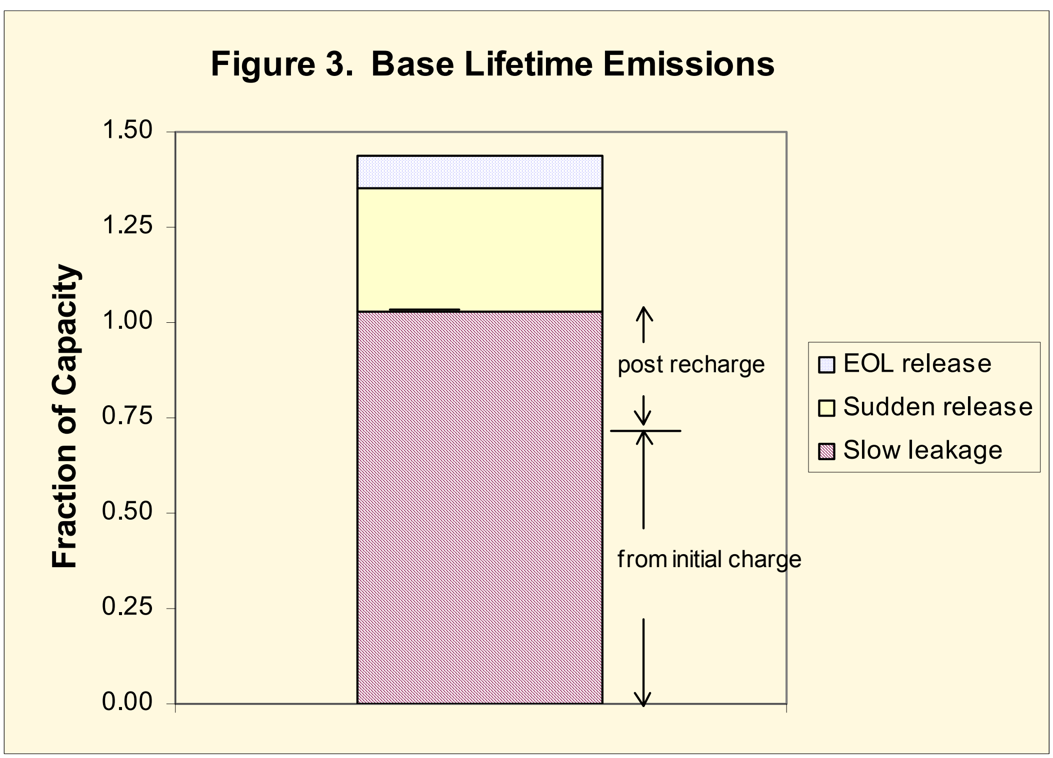


Figure 3. Base Lifetime Emissions
Fraction of Capacity
1.50
1.25
1.00
0.75
0.50
0.25
0.00
post recharge
from initial charge
EOL release
Sudden release
Slow leakage

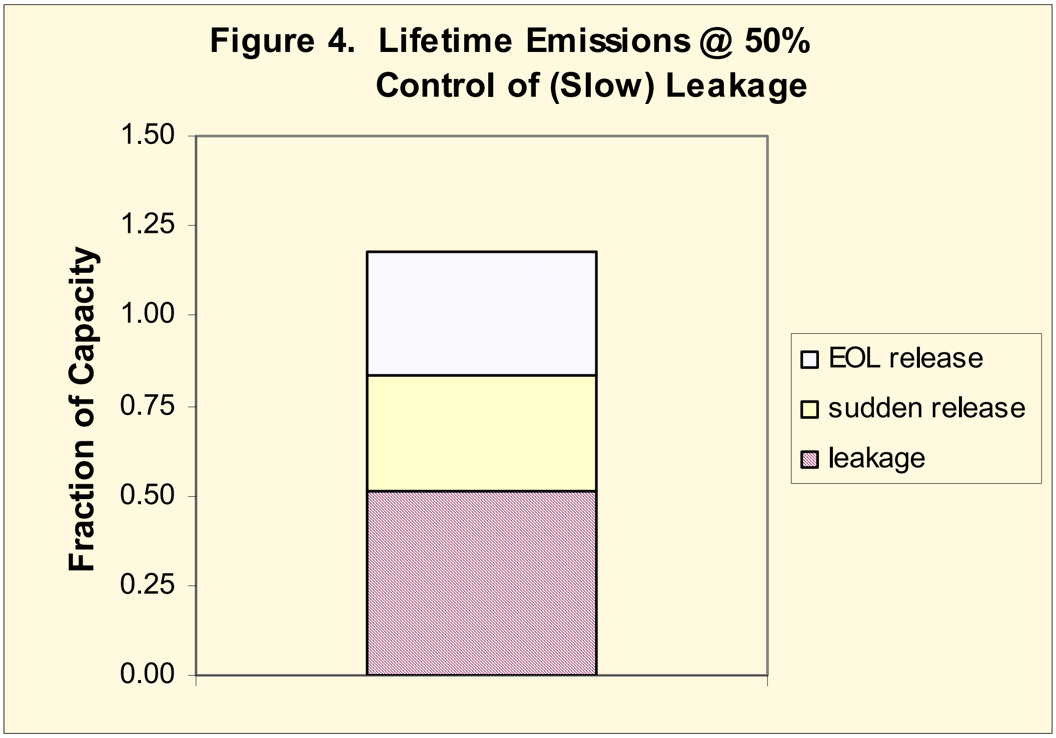
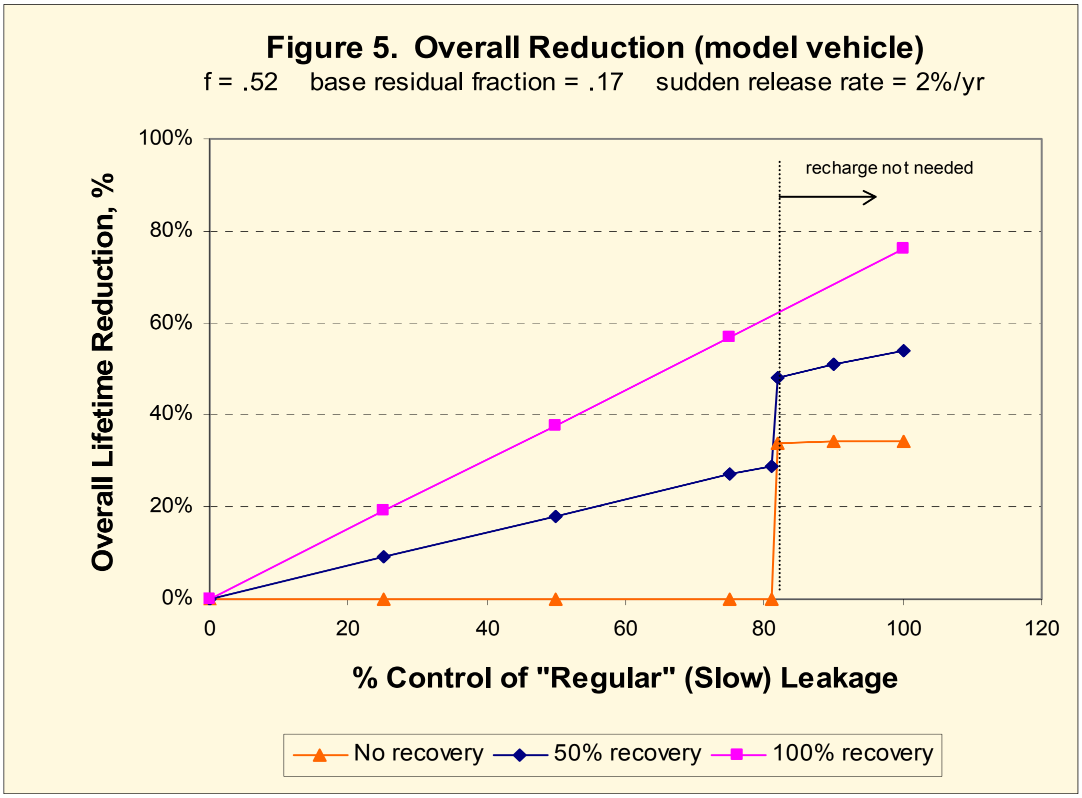


Table 1. Overall Reduction vs. % Control of Leakage and Rate of Recovery (model vehicle)

f =.52 **Sudden loss rate: 2% /yr** **Base line residual charge = .17**

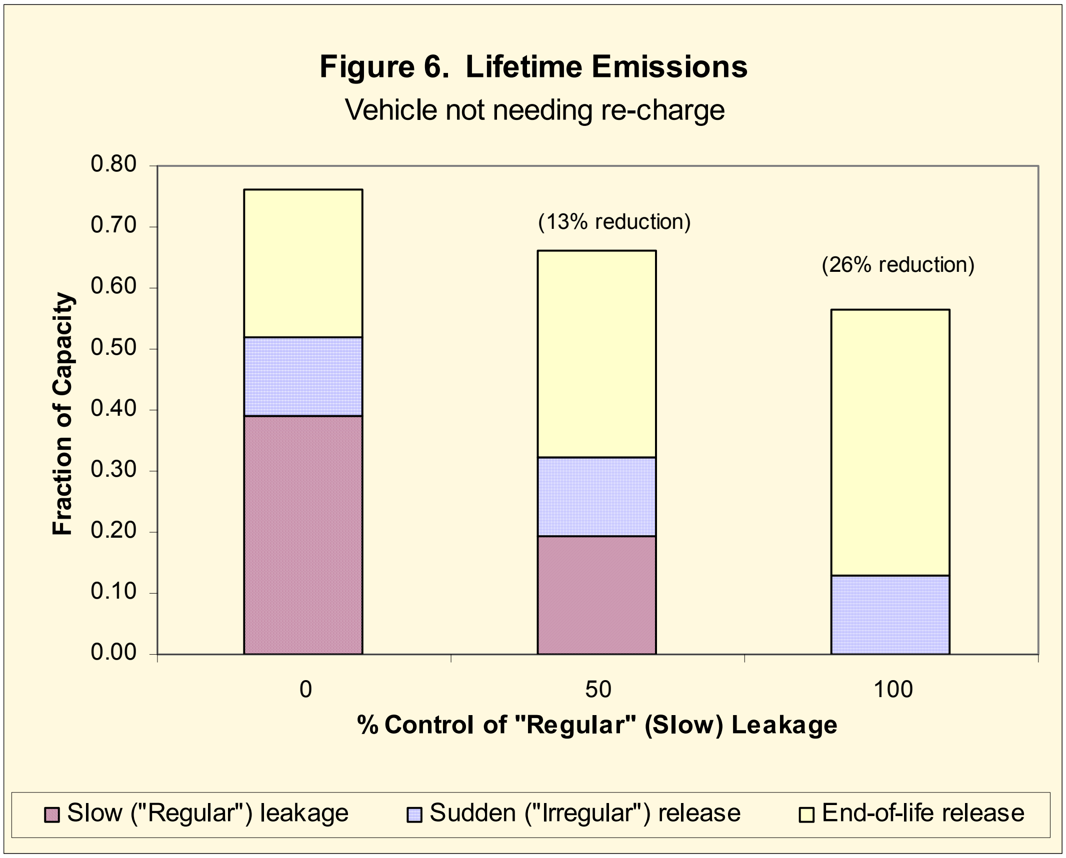
% Control	% Recovery	Age of recharge	Residual charge	Sudden release	Leakage	EOL Release	Total loss	Overall reduction
			|- - - - - -	- - - - - capacity units	- - - - -		- - - - - - |	
0	0	6.16 yrs	0.17	0.32	1.03	0.17	1.52	0%
25	0	7.6 yrs	0.43	0.32	0.77	0.43	1.52	0%
50	0	10 yrs	0.68	0.32	0.52	0.68	1.52	0%
75	0	14.4 yrs	0.94	0.32	0.26	0.94	1.52	0%
81	0	16	1.00	0.32	0.20	1.00	1.52	0%
82	0	none	0.50	0.32	0.19	0.50	1	34%
90	0	none	0.58	0.32	0.10	0.58	1	34%
100	0	none	0.68	0.32	0	0.68	1	34%
0	*50*	*6.16 yrs*	*0.17*	*0.32*	*1.03*	*0.085*	*1.435*	*0*
25	50	7.6 yrs	0.43	0.32	0.77	0.21	1.31	9%
50	50	10 yrs	0.685	0.32	0.52	0.34	1.18	18%
75	50	14.4 yrs	0.94	0.32	0.26	0.47	1.05	27%
81	50	16	1.00	0.32	0.20	0.50	1.02	29%
82	50	none	0.50	0.32	0.19	0.25	0.75	48%
90	50	none	0.58	0.32	0.10	0.29	0.71	51%
100	50	none	0.68	0.32	0	0.34	0.66	54%
0	100	6.16 yrs	0.17	0.32	1.03	0	1.35	0%
25	100	7.6 yrs	0.43	0.32	0.77	0	1.09	19%
50	100	10 yrs	0.68	0.32	0.52	0	0.84	38%
75	100	14.4 yrs	0.94	0.32	0.26	0	0.58	57%
100	100	none	0.68	0.32	0	0	0.32	76%



VEHICLE RECEIVING NO RECHARGE

In the baseline, this example vehicle reaches the point of needing a recharge (52% loss of the initial charge) at the time it is scrapped. As for the model vehicle, we assume a constant emission rate (leakage plus sudden release), an allowance of 2% loss of charge per year to account for sudden releases, and 50 percent recovery at scrapping.

Figure 6 shows the baseline emissions and emissions if leakage is controlled by 50 percent or 100 percent. At 50 percent control, the overall lifetime reduction is 13%.



If there were no recovery, the overall reduction for this vehicle would be zero regardless of degree of leakage control. At 100% recovery, the overall control would be the same as the top line in Figure 5, maximum 76% recovery for total leakage control.

Analysis Based on N'

In this calculation, each value of N' (Table 2 k in Section B "Quantification of Vehicular HFC Emissions") is split into two portions, one at 25% of the N' and the other at 75%. The latter is reduced 50 percent to account for control of slow leakage, and the 25% portion is added back. The resulting adjusted N" values are summed to N = .61 lifetime recharges. That value used in the mass balance model (lifetime emissions = C * [1 - g + N * f]) yields 1.17 kg over 16 years. This is a 14% reduction of the baseline value, 1.36 kg.

None of the three example estimates is both rigorous and encyclopedic in its treatment of the vehicle population. However, the three results for the assumed 50 percent reduction of slow ("regular") leakage--overall control of 18%, 13% and 14%--suggest that the actual effect of improving leak-tightness of AC systems would be much less than the nominal degree of control.

SECTION D

Information on HFC-134a Recovery by Vehicle Dismantlers

Assumptions Used by Others

The U.S. EPA annually publishes a report on greenhouse gas emissions in the US. For substances that are used as substitutes for ozone-depleting substances (such as Freon®), U.S. EPA relies on a proprietary model, “Vintaging”. (See Section E.) ARB staff understands from U.S. EPA staff [15] that Vintaging assumes an average recovery at scrapping equal to 57% of the capacity of the AC system. However, there is no documentation available for that estimate because Vintaging and its contents are confidential property.

In "Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories" (2000), the Intergovernmental Panel on Climate Change (IPCC), an international organization, recommends procedures for creating national greenhouse gas inventories. IPCC suggests (without explanation) 40% as the average state of fill of AC systems reaching dismantling yards. However, their default recommendation for the fraction of that material that is actually recovered is 0. IPCC adds that some value greater than zero is appropriate if the country has an effective recovery program at dismantlers. However, IPCC neither defines an effective program nor suggests how to set a recovery fraction greater than zero.

HFC-134a Available for Recovery

The ARB staff obtained results for two studies conducted in the Netherlands[16] on the residual contents of air conditioning systems. We also received data from a large dismantling yard that, at our request, monitored their recovery of HFC-134a for three weeks. Also, we sent two questionnaires to members of the State of California Auto Dismantlers’ Association--a pilot version to eleven selected member companies and a final version to the general membership (190 members). Data were obtained from 19 members between the two surveys. The data from the final survey were analyzed in two groups that have distinct means for the amount of HFC-134a in the vehicles that were not empty. Much of the information from the survey may be based on retrospective estimation rather than actual data.

The following table summarizes the information on availability.

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[15] E-mail from David Godwin, U.S. EPA, to Richard Vincent, ARB, 7 Oct 2003.

[16] Gröniger, Luciënne and Koppenol, Arend, “Contents MAC System at End of Life”, Auto Recycling Netherland (ARN) 2002-2003

Koppenol, Arend, “Investigation STEK Working Sheets”, Netherlands Agency for Energy and the Environment, 2002.

Summary of Availability at Dismantling Yards

Source	Vehicles number	Vehicles AC empty	Veh. with Refrigerant avg. system content	Overall Avg. Availability (% of capacity)
Large CA dismantler	52	15%	50% full	42%
Dutch study - 1*	146	46%	63% full	34%
Dutch study - 2*	2047	81%	68% full	13%
ARB pilot survey	1584	57%	37% full	16%
ARB final survey				
6 yards	1150	46%	51% full	27%
2 yards	350	39%	8% full	5%
			Vehicle-weighted mean:	17%
			“ , U.S. only:	19%

* Data provided by Matti Vainio of European Commission for studies by ARN and STEK

The mean value of 17% of capacity may understate what was actually in the vehicles reflected in the table. That is the case because not all the refrigerant in a system is recoverable except by extraordinary efforts.

Recovery of Available HFC-134a

Regulations of the U.S. EPA require a dismantler to either (1) own appropriate recovery equipment, recover refrigerant from the vehicles it dismantles, and keep documentation of the proper disposal of the refrigerant, or (2) keep documentation from previous owners that the refrigerant was recovered before the dismantler acquired the vehicles. EPA Region IX staff has informed ARB staff that they occasionally visit randomly selected dismantlers to determine compliance with these provisions and that they find substantial non-compliance (up to 50%). However, enforcement actions are rare; U.S. EPA relies on compliance-assistance efforts rather than citations to encourage compliance. For on-site recovery, there is no requirement for documentation of recovery on a vehicle-by-vehicle basis.

The U.S. EPA has published a list of “EPA-Certified Refrigerant Reclaimers”, three of which have California addresses. The ARB staff has contacted the three California companies and seven others from U.S. EPA’s list. Only three of the ten (one in California) collect recovered HFC-134a from dismantlers. Their roughly estimated rates of collection total less than 3,000 pounds of HFC-134a per year, which is less about 0.1% of the material available in the U.S. (or 1% in California) if the average availability at dismantling is 17% of capacity. Three of the seven companies that do not collect HFC-134a claimed to have assiduously sought clients among the dismantlers in their areas, without success; those dismantlers claim to not have the material for sale.

The lack of HFC-134a for delivery to reclaimers does not necessarily mean that a nil amount is recovered by dismantlers. Federal regulations allow dismantlers to deliver recovered refrigerant to auto repair shops and to re-use it themselves (if they keep records of the recipients and amounts delivered). Some of the respondents to our dismantlers' survey stated that they dispose of their collected HFC-134a in those manners.

Nevertheless, although some dismantlers do recover residual HFC-134a, the evidence does not support a supposition of industry-wide, quantitative recovery. There is substantial evidence that the average rate of recovery is well less than 100%.

SECTION E

Model Used by U.S. EPA ("Vintaging")

Methodology

The methodology used by the Vintaging Model to calculate emissions varies by end-use sector. The methodologies and specific equations used by end-use sector are presented below.

Refrigeration and Air-Conditioning

For refrigeration and air conditioning products, emission calculations are split into two categories: emissions during equipment lifetime, which arise from annual leakage and service losses, and disposal emissions, which occur at the time of discard. Two separate steps are required to calculate the lifetime emissions from leakage and service, and the emissions resulting from disposal of the equipment. These lifetime emissions and disposal emissions are summed to calculate the total emissions from refrigeration and air-conditioning. As new technologies replace older ones, it is generally assumed that there are improvements in their leak, service, and disposal emission rates.

Step 1: Calculate lifetime emissions

Lifetime emissions from any piece of equipment include both the amount of chemical leaked during equipment operation and during service recharges. Emissions from leakage and servicing can be expressed as follows:

$$Es_j = (l_a + l_s) \times \Sigma Qc_{j-i+1} \quad for\ I = 1\ to\ k$$

Where:

Es = Emissions from Equipment Serviced. Emissions in year *j* from normal leakage and servicing (including recharging) of equipment.

l_a = Annual Leak Rate. Average annual leak rate during normal equipment operation (expressed as a percentage of total chemical charge).

l_s = Service Leak Rate. Average leakage during equipment servicing (expressed as a percentage of total chemical charge).

Qc = Quantity of Chemical in New Equipment. Total amount of a specific chemical used to charge new equipment in a given year *j*, by weight.

K = Lifetime. The average lifetime of the equipment.

Step 2: Calculate disposal emissions

The disposal emission equations assume that a certain percentage of the chemical charge will be emitted to the atmosphere when that vintage is discarded. Disposal emissions are thus a function of the quantity of chemical contained in the retiring equipment fleet and the proportion of chemical released at disposal:

$$Ed_j = Qc_{j-k+1} \times [1 - \{rm \times rc)\}$$

Where:

Ed = Emissions from Equipment Disposed. Emissions in year j from the disposal of equipment.

Qc = Quantity of Chemical in New Equipment. Total amount of a specific chemical used to charge new equipment in a given year *j,* by weight.

rm = Chemical Remaining. Amount of chemical remaining in equipment at the time of disposal (expressed as a percentage of total chemical charge)

rc = Chemical Recovery Rate. Amount of chemical that is recovered just prior to disposal (expressed as a percentage of chemical remaining at disposal *(rm))*

k = Lifetime. The average lifetime of the equipment.

Step 3: Calculate total emissions

Finally, lifetime and disposal emissions are summed to provide an estimate of total emissions.

$$E_j = Es_j + Ed_j$$

Where:

E = Total Emissions. Emissions from refrigeration and air conditioning equipment in year $_j$.

Es = Emissions from Equipment Serviced. Emissions in year *j* from normal leakage and servicing (recharging) of equipment.

Ed = Emissions from Equipment Disposed. Emissions in year *j* from the disposal of equipment.

[Note: Reference 5 provides no parametric values for refrigerant emissions from vehicles.]